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GREISEN AND ASSOCIATED MINERALIZATION AT SILVER MINE, MISSOURI.

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INTRODUCTION.

NINE miles west of Fredericktown, Missouri, on the west side of the St. Francis River, is a locality known as Silver Mine. It receives its name from the fact that a half century ago sulphide ores were produced there, at what was known as the Einstein mine. During the World War, wolframite was produced from the Apex mine on the hill about ¼ mile back from the river. In 1927, the Ozark Tungsten Company was sinking an incline which had been located on a shoot of wolframite about 1¼ miles west

of the St. Francis River. The workings penetrated a hard silicious-looking rock with disseminated sphalerite.

The occurrence of greisen and minerals of the tin vein type at the Einstein and Apex mine has long been known, but only briefly described in the literature. The Ozark mine is a new locality characterized by highly topazized rock with disseminated wolframite and sulphides. Cassiterite is added to the list of previously found minerals. The metasomatic alterations and mineralization at this locality are so unusual for the United States as to make this locality of much interest.

GEOLOGIC DESCRIPTION OF LOCALITY.

Silver Mine is situated within the area of crystalline rocks in southeastern Missouri known as the St. Francois Mountains.

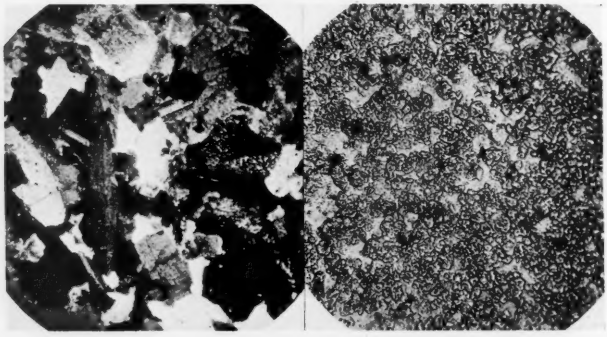

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FIG. 1. Pink granite country rock, Silver Mine. Zoned and twinned plagioclase, orthoclase, and quartz are abundant; twinned prismatic hornblende and chlorite are accessories. Crossed nicols. × 14.

FIG. 2. Topaz greisen. Topaz grains in relief against low index quartz. Small sericitic flakes are visible in quartz. × 52.

The rocks are granites and porphyries. The immediate country rock at Silver Mine is granite. The prevailing rock is a medium-grained pink granite. At the Einstein mine is a finer-grained gray granite.

The pink granite consists of quartz, orthoclase, and oligoclase in grains ranging from 1 mm. to 2½ mm. in maximum dimensions. The orthoclase shows perthitic texture and albitization. It has a fresher and less altered appearance than the plagioclase, which is generally quite turbid. The plagioclase is an acid oligoclase. It shows polysynthetic twinning and zoning. Abundant accessory minerals are hornblende and chlorite. The hornblende occurs in green pleochroic twinned crystals from ¼ mm. to 2 mm. in length. The chlorite is derived from brown mica. It is in plates 1 mm. or less in length. Sparse accessory minerals are magnetite, epidote, minute apatite prisms, and small grains of fluorite. Fig. 1 is a microphotograph of this granite. Its mineralogic composition as determined in thin section accords with the following partial analysis of a sample of granite from near Silver Mine given by Keyes.[1]

SILVER MINE GRANITE.

SiO_2	73.98
Al_2O_3	14.32
CaO	1.04
K_2O	3.32
Na_2O	4.56

The gray granite is composed of grains of quartz and feldspar ranging between ½ mm. and 2 mm. in maximum dimensions. It contains a little less quartz than the pink granite and much less orthoclase, to which is due the loss of the pink color. Most of the feldspar in this rock is plagioclase close to albite in its optical properties. It is evidently a potash-poor facies of the pink granite. The only abundant accessory mineral is green pleochroic chlorite derived from mica. It occurs in very small flakes and in patches up to 1 mm. across. Pyrite and magnetite and opaque white spots of leucoxene are minor accessory constituents. Minute needles of apatite are abundant. A small streak of fluorite passes into chlorite, which it appears to replace.

[1] C. R. Keyes, Missouri Geol. Survey, vol. 9, 1896, p. 25.

THE OZARK MINE.

In the summer of 1927 the Ozark Tungsten Company had sunk an incline 100 feet in the direction S. 65° E. with a dip of 47° and run a 50-foot drift in the direction N. 50° E. following a seam in the rock. An iron-stained breccia cemented by wolframite and quartz which was encountered at the surface had been passed through and the work was proceeding in a gray siliceous-looking rock with disseminated sulphides and traversed by veinlets and irregular fractures filled with quartz, purple fluorite and sulphides (Fig. 4).

The Greisen.—Megascopically the rock looks like a dense, fine-grained, light gray quartzite. Under the microscope it is seen to consist mainly of topaz and quartz and a minor but variable amount of sericitic mica. In some of the rock the quartz is so subordinate in amount that it consists almost entirely of topaz. Other specimens consist mainly of quartz with very little topaz. Another facies consists of quartz and sericite. The common appearance of the rock is that of an abundance of topaz grains embedded in a quartz matrix, with minute flakes and aggregates of sericitic mica scattered throughout. The photomicrograph, Fig. 2, illustrates this type of rock.

The usual grain size of the rock is very fine. Topaz occurs in anhedral, more or less rounded grains, about .04 mm. in diameter. Quartz grains average somewhat larger; the largest single grains and quartz aggregates have a diameter of .3 mm. Most of them have anhedral interlocking boundaries. Thin sections show a few hexagonal outlines of euhedral crystals. A few larger quartz grains which include no topaz are up to .5 mm. in diameter. They contain a nucleus of older quartz, remnants of the original quartz of the granite, which is surrounded by a zone or rim of later quartz deposited as part of the process of greisenization (Fig. 5). Sericitic mica occurs in patches 1 mm. or more in size or in flakes intimately associated with both quartz and topaz. It tends to occur interstitially but also replaces both quartz and topaz. The photomicrograph, Fig. 3, shows the texture of topaz-poor greisen. The quartz is somewhat more coarsely crystallized and

the secondarily-enlarged grains of granite quartz are more abundant. The sericite occurs between the larger quartz grains and replacing them and generally includes many smaller quartz grains. But even in this rock .5 mm. is about the maximum grain size. There are also a few minute short prismatic crystals of topaz, unlike the usual rounded anhedral grains.

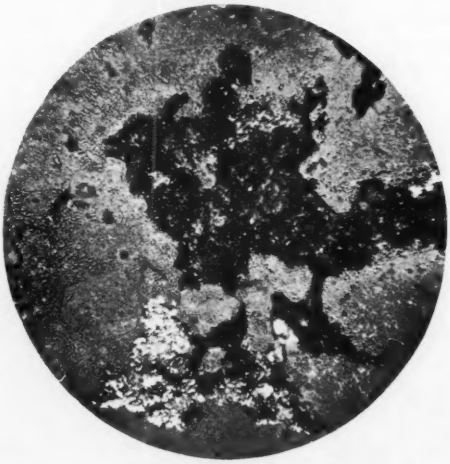


FIG. 3. Greisen consisting mainly of quartz and sericite with remnants of granite quartz. The mineral with high relief is fluorite. Black and dark gray areas are wolframite and sphalerite respectively. The blurred white areas are pyrite. Transmitted and reflected light. × 62.

The greisen represents an almost complete transformation of the granite. The granitic texture has been entirely lost and the feldspars wholly transformed to topaz and sericite. Most of the quartz of the granite has been dissolved and redeposited. The centers of the enlarged quartz grains appear to be the only remnants of the granite. The greisenized rock has been thoroughly permeated by magmatic solutions which introduced fluorine and largely removed alkalies and iron.

Later Disseminated Minerals.—Throughout the greisen occur fluorite and a group of ore minerals, wolframite, sphalerite, chalcopyrite, pyrite, and galena. Locally large crystals of pyrite predominate, but generally sphalerite is the most abundant and easily recognized ore mineral in the hand specimens. Fluorite is

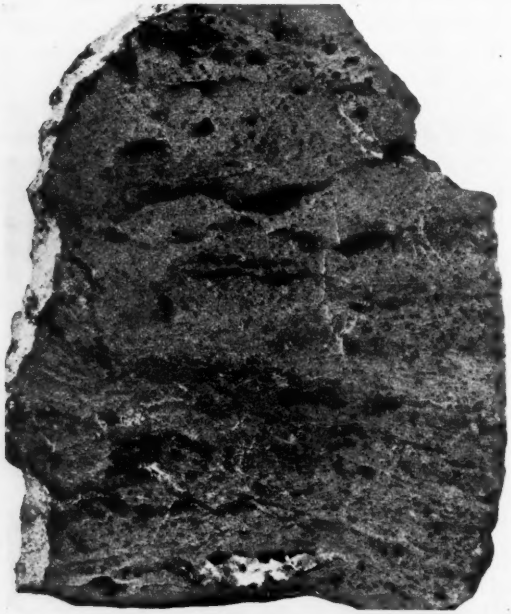
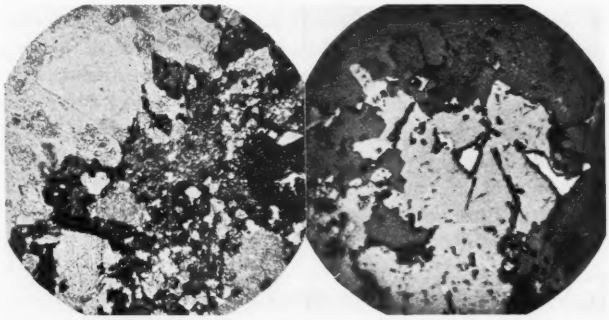


FIG. 4. Topaz greisen with disseminated ore. Natural size.

seen more readily in thin section than megascopically. The sphalerite occurs in small spots ranging from a pin point to pin head in size; interspersed with these are larger spots from 2 mm. to 5 mm. in size; still larger areas and streaks up to 10 mm. in diameter are abundant locally, take on a more or less linear arrangement, and impart a banded appearance to the rock (Fig. 4).

In other places the rock is traversed by a branching and intersecting network of veinlets which rarely have a width of 2 mm. and generally are only a fraction of a millimeter wide.

Fluorite occurs throughout the greisen in isolated patches, streaks, and connecting veinlets, with or without the association of ore minerals. Megascopically the fluorite is purple. It also shows a deep purple in inclined illumination on polished surfaces. In thin section it is colorless to purple. It was introduced by replacing the minerals of the greisen. This relation is clear in the irregular patches and streaks, but is very striking in narrow wavy



5 6

FIG. 5. Topaz-sericite-quartz greisen with remnant of granite quartz in contact with veinlet of ore consisting of fluorite replaced by sphalerite (dark gray) and wolframite (black). The small white areas with high lights are pyrite. Transmitted and inclined reflected light. $\times 46$.

FIG. 6. Ore minerals replacing quartz (light gray) and fluorite (dark gray). A large area of sphalerite has many blebs and rods of chalcopyrite (smooth white) and several larger areas of galena (white with black borders). Vertical reflected light. $\times 28$.

veinlets with irregular and ragged walls that traverse the greisen. Topaz was more resistant and grains of it are often included. The period of deposition of fluorite coincided closely with that of sphalerite. But in many places sphalerite has replaced fluorite (Fig. 5). Some of the sphalerite areas include coarsely crys-

tallized fluorite. Fluorite began to form earlier than sphalerite and extended into the period of sphalerite deposition.

The mode of occurrence of sphalerite is similar to that of fluorite. It forms irregular patches with very ragged outlines (Fig. 3). The patches include relicts of quartz, sericite and topaz. It seems to have replaced quartz and sericite more readily than topaz. Under the microscope, the intersecting veinlets are seen to be not fillings of minute fissures but discontinuous replacement veinlets with very irregular and ragged boundaries.

Chalcopyrite occurs chiefly as minute inclusions in sphalerite. In polished sections they show the characteristic blebs or points and dashes oriented in systems of parallel straight lines so characteristic of chalcopyrite in sphalerite (Fig. 6). Chalcopyrite is not confined, however, to these inclusions. Larger areas of chalcopyrite include rounded grains of pyrite or surround and replace in part pyrite aggregates. In one such area sphalerite is in contact with chalcopyrite but not with pyrite. Since pyrite is the oldest mineral, this indicates that sphalerite followed the chalcopyrite in this instance. Chalcopyrite is rarely in contact with or included by galena. Chalcopyrite also occurs associated with the other ore minerals.

Galena is least abundant of the ore minerals in the greisen. It is usually associated with sphalerite, against which it shows replacement boundaries. It often forms thin rims around sphalerite grains (Fig. 6). Occasionally it is in contact with wolframite which it has also replaced. It is always the latest of the ore minerals.

Pyrite is very irregular in its distribution. Where abundant it is coarsely crystallized, crystals and aggregates attaining several millimeters in diameter. It occurs to a limited extent in the wider sphalerite veinlets (Fig. 5). Remnants of pyrite in chalcopyrite were described in discussing that mineral. Euhedral pyrite crystals are cubes. The mineral precedes the other ore minerals.

Wolframite is more abundant than megascopic examination suggests because it looks so much like sphalerite. In thin sections and polished sections it is more readily recognized. It occurs

closely associated with sphalerite (Figs. 3 and 5) and alone in the same way as sphalerite. Some sections contain more wolframite than sphalerite. It is nearly opaque in thin section. Most grains show a reddish brown color in inclined reflected light, but some have a gray metallic luster similar to that of magnetite. When intimately interlocking with sphalerite, it is easily distinguished on polished sections viewed in inclined illumination under the binocular microscope.[2] Its greater hardness makes it stand out in slight relief. Occasionally wolframite seems to replace sphalerite and some sphalerite is surrounded by wolframite, indicating that the wolframite is younger than the sphalerite. In most cases the minerals appear to have been deposited at the same time. Wolframite replaces fluorite (Fig. 5).

The minerals introduced into the greisen made their way by replacement (Fig. 4) sometimes following lines of minute fractures. Sericite was the most easily replaced, and topaz the most difficultly replaced mineral of the greisen. The sequence in which they were introduced was fluorite, pyrite, chalcopyrite, sphalerite, wolframite, galena. The periods of deposition of the minerals overlapped greatly and those of chalcopyrite, sphalerite, and wolframite almost coincided.

The Tungsten Ore.—The tungsten ore upon which the Ozark Tungsten Company's workings had been started was not seen in place, but specimens were secured from sacks of it stored at the mine office. Megascopically it looks like a breccia of iron-stained rotten chert cemented with wolframite and quartz. The cement

[2] The utility of the binocular microscope in examining polished sections in inclined reflected light is worth calling attention to. It brings out more clearly and strikingly differences in relief which are expressions of differences in hardness between the minerals of the polished surface. Even more valuable is the penetration it permits beneath the surface, giving a three-dimensional view of the boundary relations between ore minerals and gangue minerals, especially when a strong source of illumination is used. Boundary outlines in the plane of the section do not begin to tell the story that is revealed by this look down into the specimen. The use of inclined illumination with the metallographic microscope to observe these phenomena is common practice, but they are brought out so much more clearly with the binocular that it is believed a service is performed in calling attention to its advantages inasmuch as no mention is made of this use of the binocular in any of the books on the metallographic method applied to ores.

did not completely fill the larger spaces between the rock fragments, so that the ore is porous and drusy. The cement is also highly iron-stained due to extensive oxidation of the wolframite and the formation of limonitic-looking gossan.

Under the microscope the rock is seen to be topaz greisen traversed by rusty iron-stained fractures. It includes very little quartz and some patches of minute mica flakes. Along the boundary between wolframite and the topaz rock, the topaz is coarser-grained, some of the grains being as large as .2 mm. in

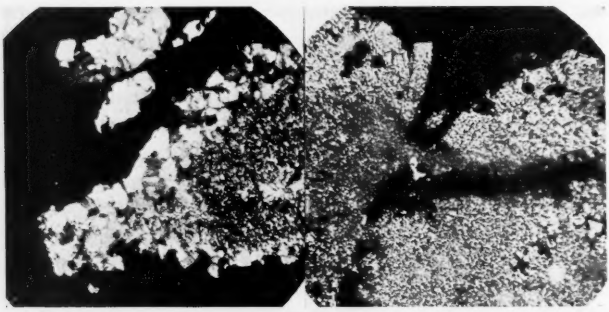


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FIG. 7. Wolframite (black) replacing topaz rock. Topaz is more coarsely crystallized along the contacts with wolframite. The center of the large topaz area shows the normal grain size of the topaz rock. Crossed nicols. × 40.

FIG. 8. Wolframite veinlets in topaz rock extending from larger wolframite mass. Boundary relations show replacement of topaz rock. The clouded zones along the veinlets are due to alteration of wolframite to ferritungstite, goethite, and limonite. The limonitic stain spreads far beyond the original veinlets, but the ferritungstite and goethite are deposited largely *in situ*. Transmitted and inclined reflected light. × 50.

diameter (Fig. 7). It is evident that where wolframite was introduced, the topaz was dissolved and in part recrystallized. Many veinlets of wolframite traverse the topaz rock, and they are bordered by coarser topaz. Though the wolframite was intro-

duced in the spaces between the breccia fragments and along fractures in them, it has extensively replaced the topaz along the contacts of the two minerals (Figs. 7 and 8). The stronger iron-stained fractures were originally wolframite veinlets in which the wolframite has been completely oxidized. The oxidation products are aggregates of considerably iron-stained pale yellow platy crystals and goethite (Fig. 8). The yellow platy crystals have high index of refraction and high double refraction and seem to be uniaxial negative. The mineral is doubtless ferritungstite. Larger masses of wolframite have also been altered into these same minerals.

The wolframite varies in color in thin section from almost opaque black with only occasional spots showing faintly dark red to translucent deep blood red. There is a corresponding variation in the color of the streak from dark brown to light yellow-brown. It gives a pronounced manganese reaction. Fused alone before the blowpipe it is not magnetic. Fused with a little sodium carbonate and crushed, many of the fragments are picked up by a magnet. These properties suggest that it is a wolframite with variable manganese-iron ratio. Frequently there are regular intergrowths of the black wolframite in the red wolframite. In one thin section of the wolframite are similar intergrowths of a translucent yellow substance that seems to be an intimate mixture of an isotropic and an anisotropic mineral. Dr. W. T. Schaller suggested that it may be an intergrowth of sphalerite and wurtzite in the wolframite. There was not enough of this material to make a conclusive determination of it. Where the wolframite penetrates the greisen, it is accompanied by little or no quartz (Figs. 7 and 8). In the filling of the interstices of the breccia fragments, the wolframite is associated with much quartz. Megascopically it is obvious that the quartz is later than the wolframite. It fills openings left by the wolframite and traverses the wolframite along fractures and cleavages. The relations are seen more clearly in thin section (Fig. 9). The wolframite was fractured and shattered. Quartz entered along these openings, filling them and enlarging them by replacing wolframite.

The Gossan.—The extensive oxidation of the wolframite has already been referred to. Large masses in the breccia cavities have been converted into soft, ochreous gossan. This limonitic-looking material gives a strong tungsten reaction when boiled with hydrochloric acid and tin added. It was also treated with hot potassium hydroxide and the filtrate gave a strong tungsten reaction. Microscopic examination shows the gossan to consist mainly of limonite and goethite.

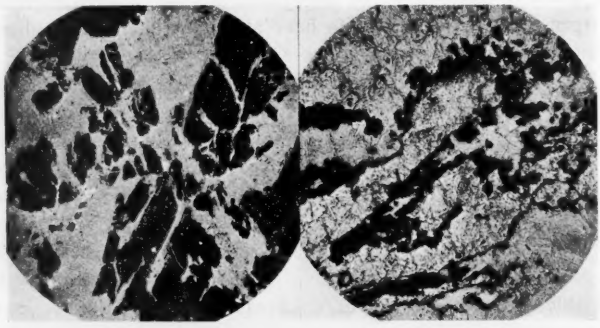

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FIG. 9. Wolframite shattered and recemented by quartz. Wolframite has been in part replaced by quartz. Transmitted and inclined reflected light. × 14.

FIG. 10. Coarse-grained topaz rock with some sericite (high index mineral at top), replaced along veinlets by coarse zinnwaldite (low index foliated mineral). The latter traversed and replaced by fluorite (highest relief mineral across center). The black grains are cassiterite. × 50.

Associated with the iron oxides of the gossan are many small lustrous aggregates of minute micaceous-looking scales. Their true color is generally obscured by iron stain, but clean aggregates have a yellowish white color. The aggregates are usually considerably smaller than a pin head. When crushed on a slide and viewed under the microscope, it is seen that they consist of great numbers of tiny hexagonal platy crystals. The largest of the hexagons are .02 mm. in diameter. The centers of the crystals

are less transparent and pale yellow in color. This nucleus is surrounded by a clear transparent colorless zone. They appear to be basal sections of a negative uniaxial mineral, showing almost complete extinction. The index of refraction along the supposed *C* axis is a little over 1.72. The crystals are decomposed by strong hot hydrochloric acid and give a tungsten reaction with tin, but are apparently unattacked by hot potassium hydroxide. The mineral is evidently ferritungstite.[3] Its presence in the ochreous gossan accounts for the tungsten reaction with hydrochloric acid and tin described in the preceding paragraph.

The gossan also contains a very little of a brilliantly lustrous mineral with tetragonal outline. It has very high index of refraction and birefringence. Due to its translucent character, it does not give a clear figure, but it appears to be uniaxial negative. It is probably stolzite. Hess [4] mentions the occurrence of stolzite at this locality. Since stolzite is soluble in potassium hydroxide, its presence would explain the tungsten reaction obtained when the gossan is treated with this alkaline hydroxide. In working on the determination of this mineral some comparative tests were run with known scheelite. It was found that scheelite is readily attacked in a boiling solution of potassium hydroxide. On acidifying the solution with hydrochloric acid and adding tin a strong tungsten reaction is obtained. Scheelite is, therefore, soluble in strong potassium hydroxide though it was found to be insoluble in tenth normal solutions of alkali hydroxides.[5]

We thought we saw some small pieces of secondary scheelite in the gossan but failed to secure large enough or abundant enough pieces to distinguish from stolzite. Ross and Henderson [6] mention scheelite among the minerals at the Einstein Silver Mine. In one thin section adjoining a veinlet of wolframite in topaz rock

[3] Waldemar T. Schaller, "Ferritungstite, a New Mineral," *Amer. Jour. Sci.*, 4th Ser., vol. 32, pp. 161–162, 1911.

[4] Frank L. Hess, U. S. Geol. Surv. Bull. 652, p. 35, 1917.

[5] R. W. Gannett, "Experiments relating to the Enrichment of Tungsten Ores," Econ. Geol., vol. 14, p. 70, 1919.

[6] Clarence S. Ross, and E. P. Henderson, "Topaz and Associated Minerals from the Einstein Silver Mine, Madison County, Missouri," *Amer. Min.*, vol. 10, p. 443, 1925.

are a few small grains of either stolzite or scheelite. They appear to be a hypogene mineral and are probably scheelite.

Another mineral recognized in the gossan occurs in aggregates similar to the ferritungstite aggregate but of white snowy appearance and less brilliant lustre. Under the microscope, the disintegrated aggregates consist of ragged flakes of a micaceous looking mineral. The flakes give a small angle, negative interference figure. They have the appearance of sericitic muscovite. The mineral is too minute in size and quantity to determine conclusively whether it is muscovite or kaolinite.

THE APEX MINE.

A quarter mile back from the St. Francis River, on the hill above the Einstein silver mine, is the Apex mine. It consists of two inclines that were inaccessible in 1927. They were worked for tungsten ores a short while during the World War. The ores were treated in a 5-stamp mill equipped with jigs and tables on the site of the old silver mine beside the river. Mining had been done at this site long before, however, because Haworth [7] in 1888 spoke of abandoned operations at the Apex shaft. He says the Apex Shaft was sunk on the southwestward continuation of the same vein worked at the Einstein mine. Here it was characterized by a higher wolframite content. Our observations were necessarily confined to an examination of material on the dumps of the two inclines, which is similar to that on the Einstein mine dump.

EINSTEIN SILVER MINE.

This is the mine from which the locality takes its name. It is situated at the foot of the hill on the west bank of the St Francis River below a dam which was built across the river to furnish power for the operations. The workings are no longer accessible and observations were restricted to an examination of dump material.

Earlier Descriptions.—Though the interesting mineralization at this locality is referred to a number of times in the literature of

[7] Erasmus Haworth, *Amer. Geologist*, vol. 1, p. 295, 1888; also Missouri Geol. Survey, vol. 8, p. 160, 1894.

Missouri geology, the references are brief and add little to the two short paragraphs contributed by Haworth[8] in 1888. His description is as follows:

"The vein itself extends from the west bank of the St. Francois, back in a southwest direction for an unknown distance. Years ago mining operations were carried on in an almost fruitless search for silver. At the time of my visit to the place the works were abandoned, the shafts and tunnels filled with water, so that almost the only available material was in the 'dump pile.' . . . The vein itself was filled with quartz, argentiferous galena, fluorite, lepidolite, wolframite, and probably other minerals. The wall-rock was originally granite. At present, however, it consists of quartz imbedded in a fine-grained mixture of mica scales with traces of iron oxide, leucoxene, beautiful little zircon crystals, and probably other materials. Scattered through the mass in varying proportions are the minerals fluorite and topaz."

In 1894, Haworth[9] again described the occurrence. He called the lithium-bearing mica zinnwaldite and described the occurrence of the topaz in grains of irregular shape without perfect crystal outlines. The strike of the vein was given as northeast-southwest and the dip 60° to 70° to the southeast. The sericitic alteration of the wall rock was said to extend 10 to 12 feet or more from the veins. Fluorite is more abundant in the vein than in the altered granite.

Other descriptions of the occurrence are by Winslow,[10] Keyes,[11] Buehler,[12] and Spurr.[13]

Winslow and Keyes reproduce a map of the mine after W. B. Potter, and give some historical data. The strike of the vein is stated to be south of west and the dip 45° to 60° south. Its width varies from 2 to 6 feet. A tunnel 200 feet long was driven in on the vein and an incline of 180 feet sunk from which several drifts were started. The property was entered as mineral land in

[8] *Op. cit.*

[9] Erasmus Haworth, Missouri Geol. Survey, vol. 8, pp. 157–161, 1894.

[10] Arthur Winslow, Missouri Geol. Survey, vol. 7, section 2, pp. 701–702, 1894.

[11] Charles R. Keyes, Missouri Geol. Survey, vol. 9, Sheet Report No. 4, pp. 83–86, 1895.

[12] H. A. Buehler, Biennial Rept., State Geologist of Missouri, pp. 97, 98, 1919.

[13] J. E. Spurr, *Eng. and Min. Jour.*, vol. 123, p. 364, 1927.

1855. After several years of prospecting it was acquired by Knox and Einstein, who began systematic prospecting in 1877. Development work commenced in 1879 upon the formation of the Einstein Silver Mining Company which, however, lasted only a few years. In the early nineties an attempt was made to resume operations. Keyes said the mine produced 50 tons of lead and 3000 ounces of silver. Selected samples of the ore are reported to have ranged up to several hundred ounces of silver per ton and the assays from 1 to 148 ounces. The average of 50 assays was 46 ounces. The silver content is ascribed to the galena and no mention is made of the occurrence of silver minerals.

Buehler says three distinct veins of quartz have been opened up and development started on four others. The veins vary from a few inches to 5 feet and average about 2 feet. He calls the tungsten mineral hübnerite and says it is scattered through the quartz from the size of a pin head to massive bunches weighing 100 pounds. Pyrite and zinnwaldite usually appear where the hübnerite is bunched.

Ross and Henderson[14] describe the alteration of the granite wall rock to muscovite with the partial preservation of the granite quartz in isolated island-like areas. They also give a partial analysis of topaz from this locality and its optical properties.

Greisenization.—The wallrock of the Einstein vein is a dense light gray silicious-looking rock spotted with disseminated ore minerals similar in appearance to the greisen at the Ozark mine. In thin section it proves to be a very fine-grained topaz rock with numerous irregular grains of quartz corroded and embayed by the topaz, suggesting that the quartz represents remnants of the quartz of the granite from which the topaz rock was derived. These quartz remnants range in size up to .5 mm. in diameter and are characterized by a freedom from topaz and mica inclusions. In the topaz are small patches and narrow veinlets of sericitic mica. The latter are later than the topaz. Some of the greisen has an oily mottled-green appearance suggesting serpentine. This is due to the alteration of the topaz rock to a soft material con-

[14] *Op. cit.*

sisting of very fine scaly mica similar to the sericitic veinlets in the white topaz rock. A microchemical examination of this mica yielded a positive reaction for potassium. The flame test showed no lithium. Its index of refraction in basal sections is 1.570 $\pm$. The mineral is probably a damourite variety of muscovite. Grains of fluorite and ore minerals were introduced by replacement subsequently to the topazization of the rock.

The rock is traversed by veins and veinlets of quartz and fluorite containing the same ore minerals encountered in the greisen in disseminated form. The vein walls were brecciated in places and the vein filling includes fragments of greisen that have the same rotten cherty appearance as the greisen in the wolframite ore breccia at the Ozark mine but lack the pronounced iron staining of the latter. Along the contact of the veins and the greisen the topaz has recrystallized to a coarser grain size, the individual crystals ranging from .05 to .1 mm. in diameter.

Zinnwaldite.—The greisen is also traversed by narrow veins and veinlets of a much coarser foliated mica than that hitherto described (Fig. 10). The veinlets are up to 5 mm. or more in width and the folia 5 mm. in diameter. The massive mica has a light brown color. The individual flakes have a pronounced silvery sheen modified by a pale brownish tone. The index of refraction in the basal plane is 1.570 $\pm$ and 2 V is 30° $\pm$ 10°. The mineral gives a strong lithium flame. A partial chemical analysis of carefully separated flakes of the mica made by Penniman and Browne showed 0.583% lithium and 6.914% iron. A comparison of these data with Winchell's diagram of the lepidolite system,[15] shows that the mineral corresponds very closely to the ideal zinnwaldite at the middle point of the diagram in optical properties but has a considerable deficiency in lithium.

	Zinnwaldite.	Silver Mine Mica.
Fe	6.59 %	6.91 %
Li	1.99 %	.58 %
2V	35°±	30°± 10°
Nm	1.57 ±	1.57 ±

[15] N. H. Winchell, "Elements of Optical Mineralogy," Part 2, p. 365, 1927.

The partial chemical analysis suggests that the mineral is not a pure member of the lepidolite system, but probably tends toward the phlogopite molecule. Its lithium content is lower than that of nearly all published analyses of zinnwaldite.

The zinnwaldite has replaced the topaz, and includes within itself remnants of unreplaced topaz. For the most part the replacement is complete and the relations of the two minerals must be determined by the character of their boundaries. Some of the damourite appears to have been derived from the zinnwaldite, as veinlets of zinnwaldite grade into the sericitic scaly mica in a way that suggests the latter is an alteration product of the former, and minute veinlets of the same mica run out from larger veinlets of the zinnwaldite and traverse the greisen, fluorite, and other minerals. This fine scaly mica is identical in habit and color with the larger areas of sericitic mica that give no lithium reaction.

Cassiterite.—Of especial interest is the occurrence of cassiterite at this locality. Haworth recognized the similarity of the mineralization and the metasomatic alteration of the wallrock to that accompanying the deposition of tin ores, and remarked on the total absence of cassiterite and tourmaline. The finding of cassiterite in the ore establishes a still closer relationship to the tin vein type of mineralization. It is also a curious coincidence that at a locality called Tin Mountain, about 3 miles southeast of Silver Mine, about sixty years ago the occurrence of tin in a boss of melaphyre was falsely reported. Considerable excitement resulted and four tunnels were driven into the hillside in a fruitless search for tin.[16]

The mode of occurrence of the cassiterite is shown in figure 10. The individual grains are mostly less than .2 mm. in diameter, only a few large grains range up to .5 mm. This mineral is brown in color and not very transparent. The characteristic zoning of cassiterite is well developed. It is intimately connected with a veinlet of fluorite traversing topaz greisen and zinnwaldite, to a large extent, but not exclusively, clustered along the boundaries of the fluorite. There is also a tendency for cassiterite to cluster in the topaz along the topaz-zinnwaldite boundaries (Fig.

[16] Erasmus Haworth, *Amer. Geol.*, vol. 1, p. 380, 1888.

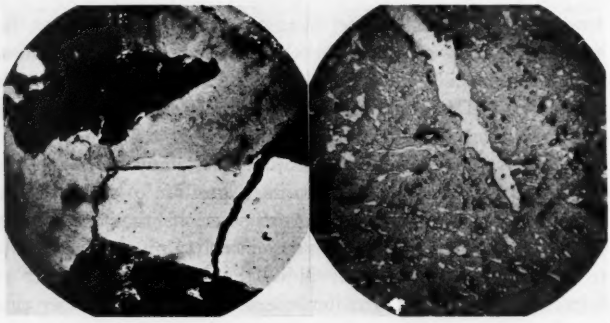
10). The topaz in the vicinity is coarser-grained than the usual greisen, grains being as large as .4 mm. in diameter. This coarser recrystallization of the topaz is found wherever later minerals have been introduced into the greisen. Grains of cassiterite extend out into the greisen away from the fluorite and zinnwaldite. Occasional grains of cassiterite in the zinnwaldite suggest that they are remnants of such grains that were included in the topaz which the zinnwaldite has replaced. The fluorite is later than the zinnwaldite. The cassiterite appears to have been introduced prior to the formation of the zinnwaldite along the same channels traversed by the solutions that formed the zinnwaldite and also after the zinnwaldite but prior to the deposition of fluorite along the same channels followed by the solutions that formed the fluorite. In other words, the sequence of mineralization was greisenization, cassiterite, zinnwaldite, fluorite, damourite, with the period of deposition of cassiterite extending over a longer time than that of zinnwaldite and overlapping the beginning of fluorite deposition.

The Sulphide Ores.—The sulphide ores consist of sphalerite, galena, pyrite, arsenopyrite and chalcopyrite in a gangue of quartz and fluorite and a little sericitic mica. Wolframite also occurs in this ore. Included in the vein filling is a great deal of the topaz rock. Much of the ore consists of shattered topaz rock penetrated by stringers and veinlets which have not only filled the fractures in the topaz rock but also replaced it along their walls.

Quartz was the first mineral deposited and is the most abundant. It is generally coarse-grained, individual grains exceeding ing 2 mm. in diameter (Fig. 11). It is in part idiomorphic against the later minerals and in part replaced by them. Its color and luster range from milky white to clear vitreous. Along the contacts with the vein quartz, the topaz rock is more coarsely crystallized, the individual topaz crystals ranging from .05 to .1 mm. in diameter.

Purple fluorite is prominent as a gangue mineral but much less abundant than quartz. It has been deposited upon the quartz and replacing the quartz. Both modes of deposition are shown in

Fig. 11. Minute scales of muscovitic mica are common along the periphery of the quartz grains, along the boundaries, between quartz and fluorite, and also penetrating the quartz and fluorite. The mica is the youngest of the three gangue minerals (Fig. 11).



11 12

FIG. 11. Gangue minerals of Silver Mine ore. Coarsely crystallized quartz (gray) is followed by fluorite (black) which fills spaces between quartz crystals and replaces quartz. The small white scales are mica, which follows the boundaries and penetrates the two earlier minerals. Crossed nicols. × 12.

FIG. 12. Chalcopyrite inclusions in sphalerite. The smaller inclusions are usually interpreted as unmixing phenomena. The large veinlet is more suggestive of replacement by chalcopyrite introduced into sphalerite. Vertical reflected light. × 28.

Pyrite and arsenopyrite are the earliest sulphide minerals. Pyrite is the more abundant. They tend to euhedral crystals embedded in the vein quartz. Pyrite is also replaced by quartz. These relations show that the deposition of quartz continued after that of pyrite.

Wolframite is embedded in quartz and certainly younger than much of the quartz. In this ore it was not seen in contact with the other ore minerals, so that its sequence with respect to them is not determined. Its relations to the quartz are similar to those of sphalerite, so that it is probably more or less contemporaneous with sphalerite.

Sphalerite is next in order of deposition. It is the most abundant sulphide in the ore left on the dumps. It is very dark in color but readily distinguished from the blacker wolframite by its brown tone and resinous lustre. In thin section it is yellowish brown. Sphalerite replaces both quartz and fluorite and occasionally pyrite.

A striking feature of the sphalerite is the abundance of chalcopyrite inclusions (Fig. 12). In polished section they show as minute blebs and rods sometimes irregularly distributed but often oriented in systems of parallel lines. Such chalcopyrite inclusions are generally interpreted as unmixing phenomena. Larger veinlets with wavy boundaries strongly suggest replacement (Fig. 12) and that the chalcopyrite in part at least is later than the sphalerite. This is further substantiated by the occurrence of chalcopyrite in tiny veinlets along the boundaries between sphalerite grains. Chalcopyrite also replaces pyrite.

Galena is the youngest of the ore minerals and replaces all the others and the quartz. It occurs in large masses and in isolated patches in the other sulphides. In the latter position, it is most commonly between sphalerite grains and in cracks in sphalerite. Galena inclusions in arsenopyrite observed in polished sections are not entirely due to replacement, but in part to filling the spaces between euhedral arsenopyrite crystals. The galena is said to be argentiferous, and selected samples are reported to have assayed from 1 to 148 ounces in silver, but no silver minerals have been noted. Our polished sections disclose no silver minerals in the galena. A sulphide concentrate was prepared by making a bromoform separation of the gangue minerals. It consisted mainly of sphalerite, pyrite, and galena, and assayed 15.28 oz. silver and 19.29 per cent lead, which is equivalent to 22.27 per cent. galena. If the silver is contained mainly in the galena, the assay would indicate a silver content approaching 70 ounces in the galena. This corroborates the high silver content credited to the galena at Silver Mine and differentiates it sharply from the galena of the nearby lead deposits in the Cambrian sedimentary formations. This content of silver in galena, though high, does not exceed the

experimental limits of solid solution of argentite in galena.[17] However, the apparent absence of silver minerals may be due to the small amount of ore available for microscopic study.

The paragenetic sequence of the vein-forming minerals is quartz, arsenopyrite and pyrite, fluorite, wolframite, sphalerite, chalcopyrite, galena. The period of formation of the quartz overlapped and extended beyond that of arsenopyrite and pyrite. Wolframite and sphalerite were deposited at about the same time. Chalcopyrite overlapped sphalerite in part. Galena was clearly the last mineral to be deposited.

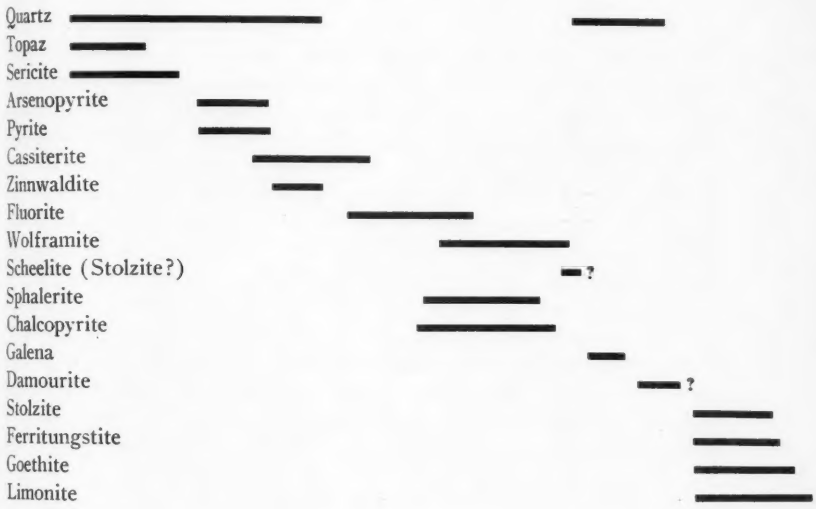
RÉSUMÉ.

Silver Mine, Missouri, is an interesting example of topaz greisenization of granite. Associated with the greisen as disseminated minerals and in veins and veinlets are most of the minerals characteristic of the tin vein type of mineralization. The present investigation has added cassiterite to the hitherto known assemblage. The lithium-bearing mica has the optical properties of zinnwaldite but contains too little lithium to be true zinnwaldite. The minerals that have been of economic importance are wolframite and argentiferous galena. Wolframite has been extensively oxidized in the gossan with the formation of the rare mineral ferritungstite. Galena with a silver content of nearly 70 ounces showed no included silver minerals.

A generalized tabulation of the paragenetic sequence of the minerals as established by the microscopic examination of the rock and the ores is given in the following table:

[17] A. E. Nissen, and S. L. Hoyt, "On the Occurrence of Silver in Argentiferous Galena Ores," ECON. GEOL., vol. 10, p. 179, 1915.

TABLE SHOWING PARAGENETIC SEQUENCE OF MINERALS.



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THE GROWTH OF MAGNETITE CRYSTALS.[1]

G. M. SCHWARTZ.

INTRODUCTION.

An investigation[2] of the mineral composition and structure of iron ore sinter has revealed much interesting and instructive information bearing on the manner in which magnetite crystals develop the euhedral form often observed in nature. It is unusual to find natural crystals showing various stages of growth, due doubtless to the slowness with which most geologic processes take place. In nature the grains are either anhedral due to interference during growth, or euhedral crystals are developed as in porphyries or vugs. Therefore, the opportunity to observe many stages in the development of artificial crystals of a substance which is also a common ore and rock-forming mineral is unusually instructive. Review of the literature shows relatively few observations or illustrations of the stages of growth of metallic crystals. In fact most of the data on the growth of crystals have been derived from a study of salts crystallizing from solution.

IRON ORE SINTER.

For a more detailed discussion of the sintering process and the nature of iron ore sinter the reader is referred to the article cited above. Only a brief outline will be given here.

The sintering process is used to agglomerate such fine material as flue dust and ore concentrate. In the case of iron ore, the mixture to be sintered consists of the iron-bearing material plus from five to ten per cent. of crushed coal and approximately the same amount of water. This mixture is spread on the sintering ma-

[1] The work on which this paper is based was aided by a grant from the research fund of the Graduate School of the University of Minnesota.

[2] Schwartz, G. M., "Magnetite Crystals in Sinters," *Eng. and Min. Jour.*, vol. 124, pp. 453–455, 1927; "Iron Ore Sinter," *Trans. Am. Inst. Min. Eng.* (in press).

chine, the fuel in the surface layer is ignited from above, and air is drawn down through the bed so that combustion proceeds from the surface downward. Combustion takes place at innumerable centers, due to the crushed fuel and forced draft. The temperatures created are very high, but last for only a few minutes, as the cold air drawn from above cools the mass as soon as combustion is completed. The time required to sinter a four inch bed may be only fifteen minutes. As the mass of fine ore fuses, a high porosity is developed by the passage of the air.

Iron ore sinter consists mainly of magnetite and fayalite with small amounts of hematite. Other constituents are usually insignificant. Magnetite is the principal iron oxide in iron ore sinter, regardless of the original nature of the iron ore, which may consist mainly of magnetite, hematite, or even pyrrhotite.

The crystals here described have developed from molten material and therefore the analogy is perhaps closest between them and magnetite found in igneous rocks. It is probable, however, that the actual development of a crystal is much the same regardless of the mode of formation. It is significant that skeletal forms of magnetite are sometimes found in diabases.[3]

Development of Crystals.—The best method of observing the mineral composition and texture of sinter is by a microscopic examination of polished surfaces. The principal minerals of sinter are hard and take a brilliant polish, which facilitates observation at the high magnifications necessary. In the present study, ranges in magnification from 100 to 1,000 were found necessary.

Examination of polished surfaces of a normal sinter reveals innumerable subhedral to euhedral crystals of magnetite embedded in fayalite. In certain areas, however, the crystals were evidently prevented from attaining full development by the sudden cooling of the sinter and many stages of growth are preserved from the initial crystallite[4] stage through skeletal forms to com-

[3] See especially the excellent paper by H. W. Lindley, Mikrographie der Eisen mineralien oberhesser Basalte, *Neues Jahrb. f. Min.*, vol. 53, pp. 323–360, 1926, in which are described magnetite crystallites in basalt similar to those found in sinter.

[4] The term dendrite is used extensively for the branching forms, but crystallite is preferable where the forms have the symmetry of crystals.

plete crystals. Some of the best early stages were found in a sinter containing 35 per cent. silica which was fused in a crucible subsequent to sintering. The mass was heated for some time at approximately 1600° C. and then the crucible was removed from the furnace and allowed to cool in open air. In this experiment most of the iron oxide was combined with the silica to form fayalite leaving relatively small amounts to crystallize as magnetite. The sudden chilling of the mass by removal from the furnace froze the mass during the process of crystallization.

In most sinter, many stages in the growth of magnetite crystals may be observed in a single specimen, often within even a single field of the microscope.

Stages of Growth Illustrated in Sinter.—Crystal growth of metallic crystals in the early and rapid stages rarely seems to take place by simple enlargement of minute crystals, but rather many minute crystals form by rapid growth along certain axes resulting in elongate branching aggregates or crystallites. Many metallic oxides and other metallic compounds apparently act much like simple metals during crystallization, and this seems true of magnetite. A study of the photographs accompanying this paper shows the form of magnetite crystallites, and successive stages as they pass through skeletal forms to complete crystals.

Fig. 1 shows a field of a polished surface of a re-fused iron ore sinter which was chilled by withdrawing from the furnace at a temperature of 1600° C. The remarkably regular arrangement of the crystallites can only be indicated in such a limited field. The crystallites consist mainly of small rod-shaped particles with short arms extending at right angles, that is, parallel to the crystallographic axes [100]. Some of the arms, presumably in the earlier stages, are rounded but others show a slightly more advanced form where the arms are truncated by the octahedron at each end. Fig. 2 shows the more regular forms which result from this tendency and doubtless represents a situation where the supply of iron oxide and heat conditions allowed slightly more growth than is represented in Fig. 1. Fig. 2 shows a few examples of a further stage where the ends of the cross arm (paral-

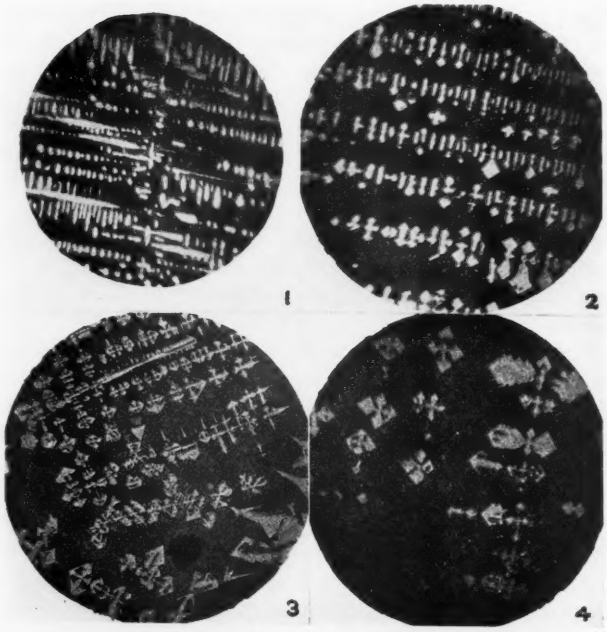

FIG. 1. Early stage of growth of magnetite (white) in fayalite (dark) Iron ore sinter containing 35 per cent. SiO_2, re-fused in a crucible. × 460.

FIG. 2. More advanced stage of magnetite crystallites. Note the tendency of small crystals to form at the ends of the cross arms. Same specimen as Fig. 1. × 460.

FIG. 3. Crystallites and skeleton crystals of magnetite in fayalite. Note the formation of larger crystals by growth from the ends of the original crosses. Sinter from Lebanon plant of Bethlehem Steel Co. × 140.

FIG. 4. Illustrates a more advanced stage of formation of large crystals by growth of crystals at end of original crosses. Same specimen as Fig. 1. × 460.

lel to [100]) enlarged to form a crystal with square outlines in the plane of the paper but arranged diagonal in the direction [110]. This general tendency of small crystals to form at the ends of the crosses is shown in Figs. 3, 4 and 5. The next stage in formation is the connecting of the ends of the crosses by diagonals [110] thus outlining a skeleton crystal. This stage is illustrated in Figs. 3 and 5. Fig. 4 suggests that growth of the crystals at the ends of the arms may result in a large crystal by coalescence of the four crystals at the ends of the crosses, and thus passing more or less directly from the crystallite to the complete crystal form, omitting the stages where the ends of the crosses are connected by diagonals.

Filling in of the skeleton crystals, formed as outlined above, ultimately results in a complete crystal, and all evidence of the manner of growth is obliterated. Fig. 7 shows a completely outlined skeleton crystal. The original cross arms [100] are clearly marked. They presumably represent the crystallographic axes and the crystal is probably an octahedron.

Fig. 8 shows a normal field of a sinter in which the magnetite has completely formed. The many straight outlines of faces indicate the relative perfection of crystal form attained. There is little evidence in any of the photographs, or from any of the numerous samples of sinter examined microscopically, that the crystals enlarge by the addition of layers around the outside. The fact that crystallites and skeletal forms are approximately of the same order of size as the completed crystals (Fig. 8) indicates that this is not an important factor in the growth of magnetite crystals.

DISCUSSION.

The conditions which favor the development of euhedral crystals of magnetite in sinter seem to be: first, the presence of sufficient silicate so that the crystals do not interfere, and secondly, sufficient time to allow arrangement of the atoms. Crystallites and skeletal forms are preserved where the supply of magnetite is somewhat limited and the time of cooling insufficient to allow the

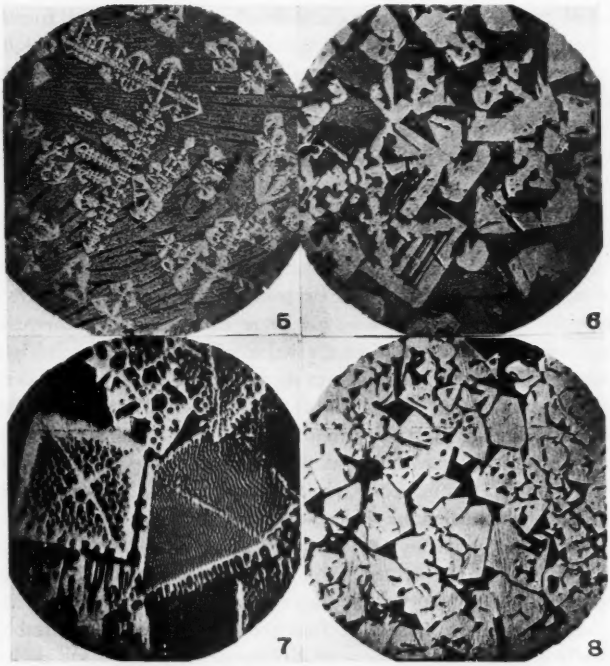

FIG. 5. Unusually perfect crystallites and skeleton crystals of magnetite. Note the tendency of magnetite to connect across from one cross arm to another, thus forming a square with the original axes of growth as diagonals. Note the sheaf structure of the fayalite groundmass. Sintered concentrate from the Shenango pit, Mesabi range, Minnesota. $\times 80$.

FIG. 6. Skeleton crystals of magnetite. Several outlined but not complete. Same specimen as Fig. 5. $\times 160$.

FIG. 7. Completely outlined crystal of magnetite. Presumably a cross section of an octahedron. Sintered mixture of 75 per cent. Fe_2O_3 and 25 per cent. SiO_2. $\times 520$.

FIG. 8. Practically complete crystals of magnetite showing outlines of many crystal forms. This is typical of most of the magnetite in sinter. Growth is practically complete. East Mesabi Iron Company sinter. Minnesota. $\times 90$.

initial crystallites to rearrange themselves into euhedral forms. Doubtless the fundamental fact which accounts for the marvelous forms displayed by magnetite is the difference in melting points of magnetite and fayalite. Magnetite [5] melts at 1538° C. and fayalite according to the latest information,[6] at about 1355° C. Doubtless the fayalite melt is amply fluid 200° C. above its melting point to permit rather free movement of the atoms which form magnetite and yet not fluid enough to permit rapid settling or segregation of the newly formed crystals.

As noted above, much of our information regarding the growth of crystals has been obtained by studies of crystallization from solution. This may be observed by reference to comprehensive treatises on crystals such as the work of Tutton;[7] Desch [8] has recently summarized the data on the growth of metallic crystals.

Regarding the incipient crystallization, Miers [9] has shown that in crystallization from a solution there are two zones of temperature-concentration where crystallization takes place. In the higher temperature zone the liquid is metastable or in a condition where crystallization by inoculation takes place. At a higher concentration or in the supersaturated zone (labile zone) crystallization takes place spontaneously. Experiments have shown that crystallization from a labile state is very rapid and results in branching, feathery, dendritic forms, whereas from a metastable state it is comparatively slow and there is adequate time for the growth of good crystals. Tutton [10] illustrates the contrast in forms produced by potassium bichromate crystallized under the two conditions. When crystallization in the labile zone has precipitated out sufficient material, the solution enters the metastable range of temperature concentration and minute crystals form at the ends of the branches of the dendrites. Possibly the examples

[5] International Critical Tables, vol. 1, p. 128.

[6] Herty, C. H., and Fitterer, G. R., "The System Ferrous Oxide-silica," *Ind. and Eng. Chem.*, vol. 21, pp. 51–57, 1929.

[7] Tutton, A. W. H., "The Natural History of Crystals," 287 pages, 166 illustrations. London, 1924.

[8] Desch, C. H., "Growth of Metallic Crystals," *Trans. A. I. M. E.*, vol. 75, pp. 526–549, 1927.

[9] Miers, H. A., *Jour. Chem. Soc.*, vol. 89, p. 413, 1906.

[10] Tutton, A. W. H., *op. cit.*, Plate XII.

shown in Figs. 2 and 4 where small crystals have formed at the ends of the axes of growth may be explained in this manner.

The dendritic forms of magnetite preserved in sinter suggest that crystallization took place under conditions analogous to the labile state in solutions. In the case of simple melts crystallization depends on cooling rather than on concentration, that is, undercooling takes the place of supersaturation. In the crystallization of magnetite from a melt containing other material both supersaturation and undercooling are involved.[11]

Desch describes the mechanics of growth which results from the crowding together of surfaces of equal concentration or undercooling that occurs at the angles of small crystals. Due to the insufficient supply to the faces when growth is rapid, the crystal tends to elongate at the angles and the rapidly advancing point enters a zone where the supply is more favorable. Thus elongated and branching forms result and each advancing point acts as a nucleus which extends by additional growth parallel to the original direction. In this manner dendrites (crystallites) and skeleton crystals are built up and eventually become complete crystals. In the usual metallic melt the crystals interfere and form anhedral grains which show no evidence of the manner of growth.

The most perfect crystallites and skeletal forms described in the literature are of snow crystals. Some of the forms shown by magnetite isolated in fayalite or iron ore sinter seem nearly as perfect as snow crystals, but the amazing variety of snow crystals is not equaled by magnetite.

The crystallization of a substance involves the arrangement of the atoms in the appropriate space lattice. The form of the crystal is necessarily an expression of the space lattice.

Bravais' law states that the stable faces are those of greatest atomic population. For the simple lattices of the metals, growth is slowest in a direction normal to the planes of greatest density. This rule may not hold for a substance with a complex structure such as magnetite is known to have.[12]

[11] Desch, C. H., *op. cit.*, p. 528.

[12] Bragg, W. H., "The Structure of the Spinel Group of Crystals," *Phil. Mag.*, vol. 30, pp. 305–315, 1915. Nishikawa, S., "The Structure of Some Crystals of

Magnetite normally develops an octahedral form which means, as can be easily seen by studying a model, that the directions of most rapid growth are parallel to the cube axes. This shows that the directions of growth illustrated by Figs. 1 to 7 are the directions of the cube axes.. This control of growth applies to the minute crystals at the ends of the crystallite arms as well as to the crystallite itself, a fact which emphasizes the rigidity of this control.

CONCLUSIONS.

It has been shown that magnetite in iron ore sinter develops euhedral crystal forms by growth starting at a nucleus and proceeding rapidly in the directions of the isometric axes, producing crystallites. Skeleton crystals are formed either by continued growth of the crystallite apparently connecting the ends of the cube axes by (111) octahedral planes, or by additional crystals growing at the ends of the axes. Filling of the skeletal forms results in the complete crystal. It is suggested that this method of growth probably applies to the formation of many magnetite crystals in nature, particularly those of magmatic origin.

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the Spinel Group," *Proc. Math. Phys. Soc. Tokyo*, vol. 8, p. 199, 1915. Gruner, J. W., Magnetite, Martite, Hematite: ECON. GEOL., vol. 21, pp. 375–393, 1926.

THE SIGNIFICANCE OF "UNSUPPORTED" INCLUSIONS.[1]

STERLING B. TALMAGE.

AMONG the frequently observed features in connection with mineral veins is the occurrence of fragments of some material foreign to the vein, apparently isolated and without contact with other fragments or the wall rock, completely surrounded by vein material in the exposed section. Such occurrences, often termed "unsupported inclusions," have been noted by various observers under a wide range of conditions, and with an equally wide range of explanations. Among the reasons that have been suggested to account for such structures may be listed:

That the inclusions must have floated free in the fluid from which the vein was crystallized.

That the inclusions are replacement residuals.[2]

That some inclusions are replacement residuals, as testified by their rounded or corroded character, but that some other explanation must be found for the angular inclusions.[3]

That angular inclusions, as well as rounded ones, may be produced by replacement, if the replacement proceeds outward from intersecting fractures in the original material.[4]

That the angular fragments have been caught in a mass of moving material, which was injected into the fissure in a state of such high viscosity that the fragments could not settle out.[5]

That the angular fragments were originally in contact, and

[1] Presented before the Society of Economic Geologists, New York, December 29, 1928.

[2] Irving, John Duer, "Replacement Ore Bodies and the Criteria for their Recognition," ECON. GEOL., 6, p. 654, 1911.

[3] Emmons, Wm. H., "Principles of Economic Geology," p. 223.

[4] Bateman, Alan M., "Angular Inclusions and Replacement Deposits," ECON. GEOL., 19, pp. 504–520, 1924.

[5] Spurr, J. E., "The Ore Magmas."

mutually supported, but that the crystallization of the vein material forced apart these formerly touching fragments so as to isolate them effectively in the vein.[6]

Several of the writers cited above have mentioned the possibility that the apparently unsupported inclusions might actually be in contact or mutually supporting outside the plane of the section, but this suggestion has been dismissed as inconsequential, or else abandoned on argumentative grounds.

A single experiment performed in the Harvard Laboratory of Economic Geology suggested that the possibilities of actually supported structures duplicating the unsupported appearance might be more important than had been previously supposed.[7] In this experiment plaster of paris fragments, colored black throughout, were piled in a box, and white plaster poured in around them. After setting, the casting was sawed in two places, and in each section a fair example of the unsupported appearance was obtained.

Experiments.—In the present series of experiments, the attempt was made to eliminate every possibility of support other than the mutual support furnished by the fragments themselves. In each experiment, pieces of a dark-colored relatively heavy material were placed in a box by stacking or piling, so as to form a structure in which the upper elements rested on the lower elements. No fastening was used, and hence no piece could be supported except by resting on or against another piece, or the bottom or sides of the box. Into this box was poured a thinly fluid material, of lighter color and lower specific gravity than the material of which the pieces were made, in such a way as not to disturb the original structure. This was allowed to set, and several sections made through each casting, and photographed.[8]

[6] Emmons, Wm. H., "The State and Density of Solutions Depositing Metalliferous Veins," *Trans. A. I. M. E.*, 76, pp. 308–320, 1928.

[7] Graton, L. C., Oral discussion before Society of Economic Geologists.

[8] Several materials were tested out before satisfactory results were obtained. For the dark heavy inclusions, sealing wax, modeling clay, putty, chocolate and soap were tried; for the light fluid, paraffin, gelatine, and vegetable fat. The final choices were, for the inclusions, soap that had been melted and colored with

Results.—In the early experiments of this series, the attempt was made to build up approximately symmetrical structures. In the first experiment, the structure was built of blocks cut to about one-half inch on a side, and of cubic or nearly cubic shape. These blocks were arranged in rows, spaced so as to support similar rows in the upper layers. Fig. 1 shows a cut through the first casting, showing the blocks in the third layer resting on the blocks in the second layer; this section did not happen to touch the first or foundation layer, which supported the whole structure. Another cut through this same casting is shown in Fig. 2, which shows in this section no evidence of support except at the left end, where some of the blocks slipped out of place. The blocks (except the four at the left end) appear to be floating free in the filling, although actually supported from below.

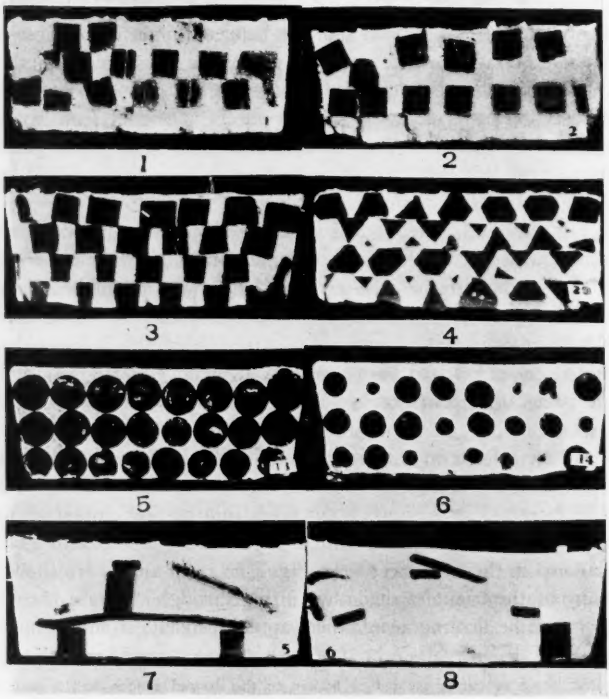
Fig. 3 shows better than Fig. 1 the supported cube structure, although even here the support is not completely visible. In no section made with the cube-structure blocks was a completely supported appearance obtained, nor with this structure was a completely unsupported appearance obtained, although it is evident that if the cubes had been perfect and arranged with geometric precision either result could follow, depending on the location of the cut.

All the cuts so far shown were vertical, in Figs. 1 and 2 parallel with one set of cube faces, and in Fig. 3 diagonal to the vertical cube faces. Fig. 4 shows a cut made in a casting similar to the one shown in Fig. 3, but with the cut made sloping as well as diagonal to the cube faces. In Fig. 4 no right angles are shown; many of the triangles made by cutting through the cube corners appear to be floating free, others appear pendent from the upper

india ink, and for the filling, the frying fat called Crisco. The soap, prepared as stated, could be cut or molded or broken to the desired shapes, had a specific gravity greater than one, and did not soften at a temperature sufficiently high to melt the Crisco completely. The Crisco had the advantage of a specific gravity less than one, a low melting point, a high fluidity, was nearly transparent while melted, and froze to a solid white mass that contrasted well with the soap. The setting required several hours in an electric refrigerator, after which the casting could be readily cut with a large knife. Each casting measured about 6 x 2 x 2½ inches.

blocks, and no block in the upper row has a visible balanced support that can be traced to the bottom. Yet the actual structure here was the same as in Fig. 3.

Another structure composed of equidimensional units was built by arranging balls of about a half inch in diameter in rows in the

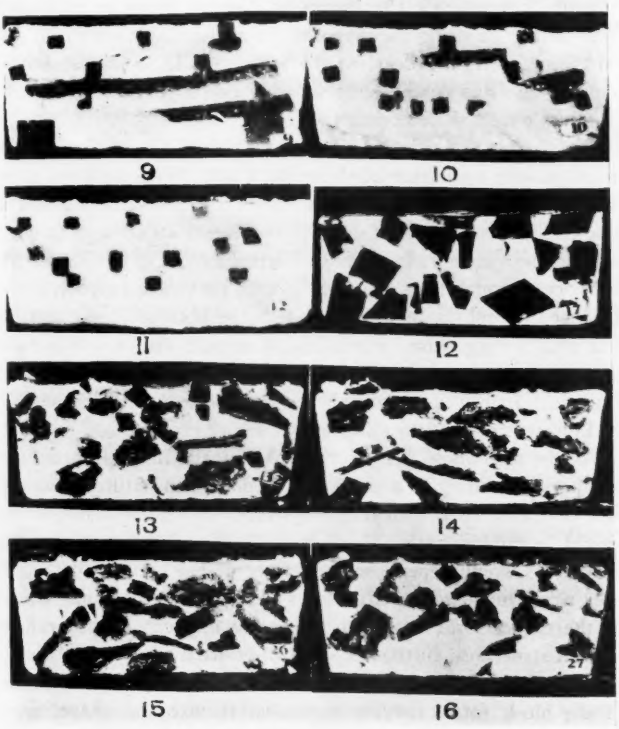


FIGS. 1–8.

box. A section through this casting is shown in Fig. 5, in which most of the balls show contact and support. Another section, taken less than a quarter of an inch from Fig. 5, is shown in Fig. 6. There are no visible contacts; the balls appear to be floating

free, but actually are the same balls which, when cut diametrically, as in Fig. 5, show such complete support.

In recognition of the fact that comparatively few of the inclusions found in nature are of the equidimensional form, experi-



FIGS. 9–16.

ments were made with structures made of units of other shapes. Four fundamental shapes were recognized, namely: (1) the block shape, nearly equidimensional; (2) the plate shape, in which one

dimension is conspicuously less than the other two; (3) the rod shape, in which one dimension is conspicuously greater than the other two; and (4) the lath shape, intermediate between the plate and the rod shapes.

One structure was built up of blocks and laths, without any attempt at symmetrical arrangement. Fig. 7 shows a cut through this casting exposing the supports, except for the one inclined lath in the upper right portion of the section. Fig. 8 shows another cut through this same casting showing no support of one unit by another, except the one near the top.

Another structure was built up of blocks, laths, and rods, laid much as one would lay kindling for a fire. Fig. 9 shows a cut through this casting in which the section exposes the support at one end, but not at the other; this represents an attempt to get a section showing a fully supported structure. Fig. 10 shows another cut through the same casting, with no visible support, either balanced or unbalanced, extending to the bottom of the section, but with a suggestion of unbalanced support visible in the right half of the section. Fig. 11 is another cut through the same casting which happened to cut only rod ends, with no support visible, and only a single contact shown.

All the sections so far described were made through structures arranged according to a preconceived plan. In nature, however, if a vein were filled with fragments from above, the arrangement would be random rather than symmetrical and the shapes of the fragments would depend on the nature of the material of which they were composed. Variation is size as well as in shape would be the natural order. In an attempt to duplicate these random natural structures, further experiments were made.

In preparing the casting shown in Fig. 12 a number of pieces of the block form, varying somewhat in size and shape, were dropped into the box from above, without any attempt being made to arrange or place them. When embedded and cut through, the result was as shown; no block shows balanced support, such contacts as are shown are point contacts rather than plane contacts, and several of the blocks appear to be floating free.

In further experiments the attempt was made to avoid any semblance of design or symmetry, and to see what patterns would be produced in sections taken through structures made by piling into the box random mixtures of blocks, laths and rods in a variety of sizes. No piece was placed, but all were dropped in or tossed in so as to duplicate as nearly as possible the structures that would occur in nature in the case of a fissure filled by fragments that fell in from above. Fig. 13 is a typical section through such a casting, showing the variety of sizes and shapes of the inclusions, with few contacts, and no visible balanced support.

Fig. 14 is a section through a similar casting, and shows a feature that is often encountered in nature, namely, the occurrence of several small inclusions apparently suspended above a larger one, illustrated by the three small blocks above the plate or lath in the left hand portion of the section. As a matter of fact these three small pieces were actually resting solidly on the inclined plate, but the points of support are outside the section. The plate itself shows one point of support at the right end, but appears to be suspended at the left end above the block on which it actually rests.

Fig. 15 is a section through a similar casting including a structure made of random pieces of various sizes, and is chosen as the one section of the whole random series that came nearest to showing or suggesting a supported structure; the inclusions are more crowded and the points of contact more numerous than in any other section of this series.

Fig. 16, another section through the same casting as Fig. 15, is chosen as the one section in the random series that shows the smallest area of inclusions, with the fewest contacts and the least visible evidence of support.[9]

Discussion of Results.—These experiments seem to prove that the appearance of isolated or suspended inclusions may easily oc-

[9] Many other sections were made, and the photographs exhibited as lantern slides, which are omitted here in the interests of space; most of those omitted show patterns intermediate between those shown in Figs. 15 and 16.

cur in a random section where the inclusions actually furnished mutual support, and were in no degree supported by the vein matter. The consistency with which this appearance occurred in all the sections of the random series (Figs. 12 to 16) indicates that this isolated appearance is the rule rather than the exception with supported structures. Therefore, the possibility of mutual support by fragments must be considered as a most reasonable one in veins, except where it can be proved that the fragments are actually separated from one another on all sides.

These experiments emphatically do not prove that all patterns showing non-contact inclusions in a random section are actually sections through supported structures. Such patterns may certainly be formed by replacement; they may be formed by fragments falling into fissures and getting caught on vein matter already precipitated, afterward being surrounded by similar material; they may be formed by fragments originally in contact being forced apart by growing crystals, and so completely surrounded by vein matter. In these and similar cases, however, the inclusions would be actually separated from one another, and so could in no section show a contact. Consequently, it may be stated with assurance that in a random section through a vein the appearance of any contacts, even a single one, proves that the fragments have not been completely separated from one another, and therefore the probability of their being mutually supporting is strong.

The suggestion that patterns composed of angular fragments showing few contacts can be formed only by viscous injection of the vein material has been made recently, and supported by other arguments.[10] The "grande antique" marble at the Hotel Roosevelt in New York City shows a pattern that it has been claimed could be due only to viscous injection of the white calcite, supporting the black fragments. An examination of this marble shows repeated instances of patterns on several scales that are very similar to the patterns obtained with these experiments on sup-

[10] Spurr, J. E., "The Ore Magmas"; also "Successive Banding around Rock Fragments in Veins," ECON. GEOL. 21, pp. 519–537, 1926.

ported structures. Moreover, the black fragments in the Hotel Roosevelt marble show numerous contacts; in fact, in certain slabs, the white calcite seems to be merely a filling of cracks in the black marble. It appears obvious that the black marble was brecciated, and the interstices filled with white calcite, probably deposited from aqueous solutions.[11] The black fragments are so plainly mutually supporting that the degree of viscosity of the filling fluid seems to be beside the question. The writer is convinced that the theory of viscous support for the black fragments in this marble, far from being the only acceptable explanation, is the least probable one that has been suggested.

In the same article the claim is made that banding around the fragments is further proof of the viscosity of the fluid medium, with reference to the Hotel Roosevelt marble and also to other occurrences. In one instance[12] photographs and diagrams are given, showing the successive banding around an apparently unsupported fragment, followed by the breaking away of a small portion, with further banding proceeding around the two pieces that have been separated. It is not explained just what degree of viscosity would suffice to support the larger piece throughout the process, and at the same time fail to support the smaller piece when it was broken off. It appears more probable that the smaller piece when broken off fell in a cavity that was open or else filled with a mobile fluid, and that the fragment stopped falling only when it rested on something solid, perhaps another fragment, perhaps the vein material deposited around another fragment, but its position indicates that it fell to a point of rest.

The theory of viscous support must stand or fall on physico-chemical grounds; it can derive no confirmation from patterns of angular, apparently "unsupported" inclusions.

SUMMARY AND CONCLUSIONS.

The patterns heretofore described as made of unsupported inclusions may be produced experimentally in structures where the

[11] Boydell, H. C., Discussion, ECON. GEOL., 22, p. 97, 1927.

[12] Spurr, J. E., ECON. GEOL., 21, Figs. 7 and 9, pp. 525 and 526, 1926.

inclusions are mutually supporting, and no support is furnished by the filling.

Similar patterns may also be produced in other ways.

With supported structures, the probability of supporting contacts being visible in a random section decreases as the fragments depart from a prevailingly equidimensional shape.

Any contacts, however few, visible in a random section prove that the fragments have not been completely separated, and consequently are strongly suggestive of a mutually supporting structure.

Failure of a random section to reveal points of support does not prove the absence of supporting contacts outside the plane of the section.

Patterns showing inclusions with few or no contacts do not prove that the fragments were supported on account of the viscosity of the vein filling. There are too many other possibilities.

The term "unsupported inclusions" has been used so widely and so erroneously that it has become misleading, and should be abandoned.

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A DIOPSIDE-BEARING PEGMATITE IN DOLOMITE.[1]

EDWARD H. WATSON.

INTRODUCTION.

In a recent number of Economic Geology, B. M. Shaub[2] has described a deposit of feldspar in crystalline limestone in New York State, which bears considerable similarity to one in Maryland occurring along the Patapsco River, about 13 miles west of Baltimore City. Shaub proposes a hydrothermal replacement origin for the New York occurrence, whereas considerable evidence indicates that the Maryland deposit is a normal pegmatite dike, using the term "dike" to mean an intrusion of magma, even though it may have been rich in volatile constituents.[3]

GENERAL GEOLOGY.

The area under discussion lies just south of the Patapsco River in Howard County, Maryland, and between the river and the Old Frederick Road. Davis Station on the Baltimore and Ohio Railroad is just north of the various localities described below. The region is accessible from Baltimore by way of the National Pike through Ellicott City to the Old Frederick Road.

Figure 1 is a sketch of this region, which consists of a series of hills sloping toward the river and with a trend parallel to the structure. A thick cover of soil conceals much of the geology.

The formations exposed are the crystalline metamorphic rocks of the Glenarm series[4] of pre-Cambrian age which, with the intrusives in them, form the eastern Piedmont of Maryland. The quartzite is thin-bedded and locally includes schistose and

[1] Published by permission of the State Geologist of Maryland.

[2] Shaub, B. M., "A Unique Feldspar Deposit near DeKalb Junction, New York," Econ. Geol., vol. 24, No. 1, pp. 68–89, 1929.

[3] Ross, C. S., Econ. Geol., vol. 23, No. 8, p. 870, 1928.

[4] Jonas, A. I., and Knopf, E. B., *Amer. Jour. Sci.*, 5th ser., vol. 5, pp. 40–62, 1923.

feldspathic facies. It is resistant to erosion and occurs in the hills. The dolomite occupies a valley between the two narrow outcrops of quartzite. It is holocrystalline, generally massively bedded, and consists essentially of calcite, dolomite, and phlogo-

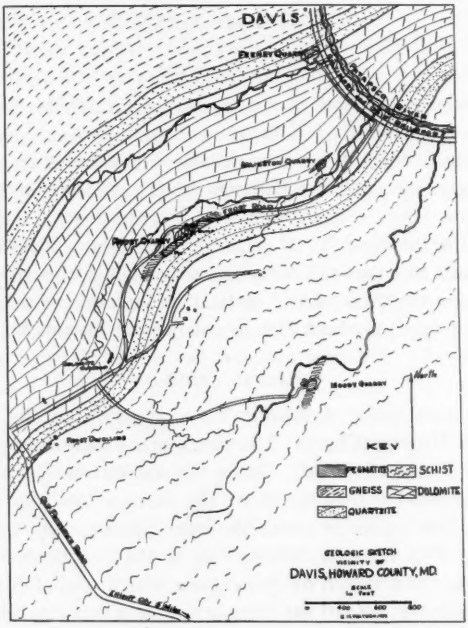

FIG. 1. Sketch showing location of pegmatites.

pite. In the outcrops of this local region it has been considerably altered. The schist is largely a quartz muscovite garnet rock, but is feldspathic in places. The gneiss is a massive quartz-feldspar-biotite rock.

The larger pegmatites are shown on the map. Smaller ones and granite dikes occur along the Patapsco River. Granite dikes also cut the Frost pegmatite. Larger masses of granite outcrop just beyond the limits of the map to the east and north.

THE PEGMATITES.

Moody Pegmatites in Schist.—As shown in Fig. 1, this body occurs in schist well away from the dolomite. It is 100 feet in width and several hundred feet long and strikes a little east of north, parallel to the enclosing rock. In composition it is nearly pure graphic granite: quartz intergrown with pink microcline. Quartz segregations occur, but are not abundant, and a few quartz veins cut the graphic granite. The dike is singularly free from plagioclase and other accessory minerals.

The schist of the east wall of the Moody quarry is extensively impregnated with pegmatite, both in lit-par-lit injections and in complete feldspathization of sections of the rock.

Feeney Quarry.—Immediately south of Davis station there is a flagstone quarry in the quartzite. An irregular, cross-cutting pegmatite, 1 to 3 feet wide, occurs at the top of the exposure. Parts of it are of pure quartz and other parts carry considerable microcline. Elsewhere in the quarry are a few thin stringers of pegmatite composed of microcline, quartz, plagioclase, and accessory tourmaline. No contact action has been effected on the quartzite by the dikes in this quarry.

Just southeast of the Feeney quarry, in exposures of dolomite along the south side of the railroad, a few pegmatite and granite dikes occur. They are small, irregular, cross-cutting bodies and are clearly intrusive dikes.

Frost Pegmatite at Schist-Dolomite Contact.—This body is exposed in a large quarry 300 feet long and 100 feet wide at the contact of the dolomite and schist. It strikes N. 55° E. and is nearly vertical. The schist is in place on the east wall of the quarry, but the dolomite-pegmatite contact is not exposed in place, though it may be seen in fragments on the dump.

The Frost quarry has already been briefly described by Bastin [5] and Singewald.[6]

[5] Bastin, E. S., "Feldspar Deposits of the United States," U. S. Geol. Surv., Bull. 420, p. 75, 1910.

[6] Singewald, Joseph T., Jr., "Notes on Feldspar, Quartz, Chrome, and Manganese in Maryland," Maryland Geol. Surv., vol. 12, p. 124, 1928.

CHARACTER OF FROST PEGMATITE.

Composition.—The essential constituents are microcline, plagioclase, and quartz. The feldspars predominate over quartz to a greater extent than is normal for the pegmatites around Baltimore. Plagioclase and microcline are in about equal amounts. Diopside is an abundant accessory. Not so abundant are hornblende, clinozoisite, phlogopite, calcite, biotite, pyrrhotite, muscovite, garnet, titanite, and apatite. Allanite is a rare constituent. Quantitatively there is considerably more diopside than all the other accessories combined.

Textures.—The minerals are intergrown in the usual coarse, irregular manner of pegmatite, though no typical graphic texture is developed. There are crystals of microcline 3 feet on a side, and plagioclase up to 18 inches across.

A peculiar intergrowth does occur, however, of microcline with quartz, in which the quartz is predominant in amount over microcline; the reverse of the normal graphic type. The quartz is in rounded bleb-like pieces within the microcline, rather than in angular rods, and in whole sections of the intergrowth, the microcline has a uniform orientation. This possibly represents a quartz replacement of microcline rather than a simultaneous crystallization, since it grades at places into large solid areas of microcline.

Segregations.—Segregations of relatively pure quartz are common; usually the quartz is distinctly subordinate to the feldspar. Plagioclase and microcline are intergrown or segregated. Their relations are often obscure since both are white in color and much of the plagioclase is untwinned.

The dark-colored minerals are nearly always grouped together in patches of a few inches to a foot or so across. As a whole, these segregations are rather uniformly distributed through the pegmatite; quantitatively they probably occupy only a few per cent. of the volume of the body. In these segregations there is a distinct and complete gradation from fine-grained patches of diopside, clinozoisite, phlogopite, and calcite to coarse aggregates of diopside. In fragments on the dump there is a further gradation from this fine-grained type with calcite to specimens of altered dolomite.

Microcline.—This mineral is white with a grayish tone, rather than the common flesh color. As stated, it is in crystals up to 3 feet across and with plagioclase is the most abundant constituent of the dike. Bastin [7] reports "microcline and orthoclase" from this quarry but in the examination of several dozen specimens no orthoclase was found. Since Alling [8] claims that orthoclase when crushed may develop microcline twinning, fragments were carefully separated with a knife and examined. Also, the goniometer gave the 89° 30′ cleavage angle of microcline. The extinction angles are 5° on 001 and 9°–10° on 010, which, according to Alling's [9] tables for the potash-soda feldspar series, would indicate a microcline with considerable albite in solid solution. However, microchemical tests show less than one per cent. of the soda molecule.

Plagioclase.—The most interesting feature of this mineral is its variation in composition. On the basis of extinction angles and indices, specimens vary from 70 per cent. ab to 90 per cent. ab. The majority are oligoclase around 80 per cent. ab. Commonly large adjacent crystals vary considerably in their content of soda.

Quartz.—The characters of this mineral are normal, and it is abundant both in segregations and in microcline-quartz intergrowths. There is considerable smoky quartz, and some is practically black in reflected light. In section it carries no more liquid cavities than is normal, but is traversed along fracture planes by films of iron oxide, to which it probably owes its color.

Diopside.—The coarse, well-developed crystals of diopside are the most striking mineral in the quarry. They are segregated in patches within the pegmatite. In the coarse segregations, individuals may reach 18 inches in length and 6 inches in width. They have a dull dark-green color and are of prismatic habit. These larger crystals are generally euhedral, though they may show some replacement by the quartz and feldspar in which they are imbedded. Frequently, also, they are broken, and the fragments are slightly separated.

[7] Bastin, E. S., *op. cit.*

[8] Alling, H. L., "Mineralography of the Feldspars," *Jour. Geol.*, vol. 29, No. 3, p. 210, 1921.

[9] Alling, H. L., *op. cit.*, p. 231.

Bastin[10] refers to this mineral as hornblende, probably because of the dark-green color. Its color and optical properties indicate a considerable FeO content, probably from the hedenbergite molecule;[11] $Z \wedge c = 40°–45°$; indices — 1.71 to 1.73.

It occurs with abundant clinozoisite in the fine-grained segregations. In these, its textures show partial replacement by quartz and feldspar (Fig. 2).

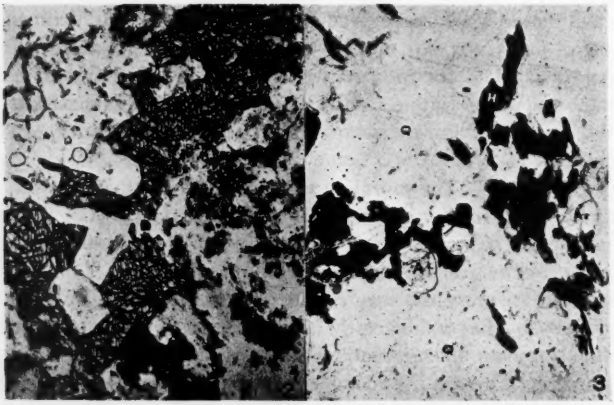

FIG. 2. Diopside replaced by microcline in altered dolomite. × 20.
FIG. 3. Hornblende replaced by quartz in pegmatite. *Q*, quartz; *A*, apatite; *H*, hornblende; *T*, titanite. × 20.

Hornblende.—Hornblende is a rare constituent, occurring as black lustrous crystals up to one inch in length associated with coarse diopside, and in somewhat greater abundance in the fine-grained segregations. In the latter it is strongly replaced (Fig. 3).

Clinozoisite.—This mineral, often with abnormal blue interference colors, is abundant in the fine-grained patches of dark minerals. It always shows extensive replacement, mainly by

[10] Bastin, E. S., *op. cit.*

[11] Winchell, N. H., and A. N., "Elements of Optical Mineralogy," p. 184, New York, 1927.

quartz. Also, almost every crystal is intergrown with vermicular quartz. Fig. 4 shows such an intergrowth, similar to the myrmekitic intergrowths in plagioclase. In Fig. 5 the quartz has entered along the cleavage planes of the clinozoisite and is clearly of replacement origin. Since there is every gradation between types illustrated by Figs. 4 and 5 and also to the more typical

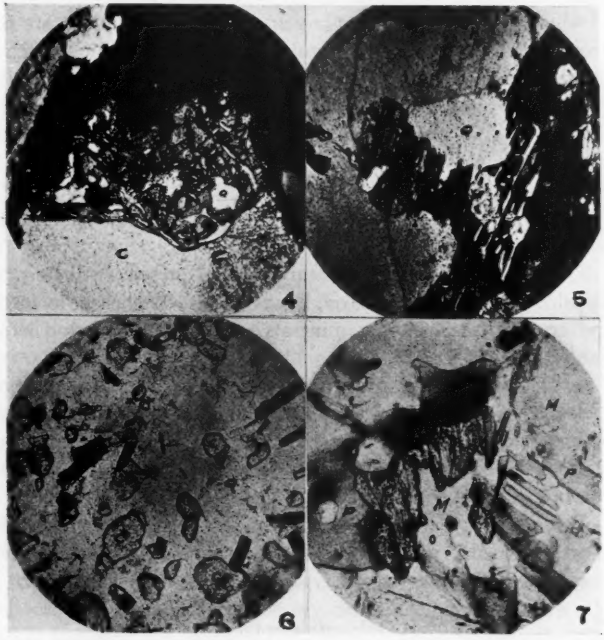

FIG. 4. Quartz-clinozoisite intergrowth. *Q*, quartz; *C*, calcite. Crossed nicols. × 70.

FIG. 5. Quartz-clinozoisite intergrowth. *Q*, quartz. Crossed nicols. × 70.

FIG. 6. Recrystallized calcite in pegmatite. *C*, calcite; *F–Q*, feldspar and quartz. × 70.

FIG. 7. Calcite remnant with phlogopite in granite dike. *C*, calcite; *P*, phlogopite; *M*, oligoclase and microcline. × 70.

replacement textures (as in Fig. 3), the vermicular quartz itself is probably of replacement origin.

Calcite.—Calcite is rather rare, and is restricted to relict patches within the fine-grained segregations of dark minerals. These relict patches are crystal aggregates similar in texture to that of the adjacent dolomite. Commonly, the pegmatite immediately adjacent to these patches is full of small round crystals of calcite, of which Fig. 6 is typical. Their arrangement and outline are not from replacement, but more probably represent solution and recrystallization of the calcite.

Phlogopite.—This is abundant in some of the fine-grained patches, and is generally associated with calcite remnants. It commonly has a peripheral arrangement around the calcite. It is differentiated from biotite by its weak pleochroism.

Biotite.—Biotite is rare; occurring as rather coarse flakes, generally with quartz.

Pyrrhotite.—Pyrrhotite is nearly always present in the coarse diopside prisms. With quartz, it was the last constituent to form, and replaces all the other minerals, especially the dark-colored ones.

Garnet.—Two types of garnet occur, both rare: (1) in large, dark-red crystals in quartz, and (2) in small, bright-red crystals with calcite, diopside, clinozoisite, etc. In the latter the garnet replaces the dark minerals and calcite, but is replaced in turn by quartz and feldspar.

Titanite and Apatite.—These are present in all the segregations in well-formed crystals, especially the titanite. They are more abundant in the fine-grained type of segregation.

Dolomite Contacts.

Composition.—All the dolomite on the dump gives evidence of extensive alteration. Its constituents may be divided into three groups: (1) original minerals of the dolomite—chiefly carbonates and phlogopite, with a little tremolite; (2) reaction minerals—diopside, clinozoisite, garnet, some of the phlogopite, titanite, and apatite; and (3) pegmatitic minerals—microcline, plagioclase, and

quartz. The proportions of these mineral groups vary from specimens in which the carbonates are predominant to those where the reaction silicates and pegmatitic minerals form the bulk of the rock. Also, the individual minerals are of irregular occurrence; at places diopside is the main reaction silicate, at others clinozoisite; among the introduced pegmatitic minerals either quartz, microcline, or plagioclase may predominate in any specimen. No apparent uniformity in these proportions can be noted.

Textures.—Where the carbonates are still present in large amount the texture of the dolomite is gneissic, as in the unaltered rock, but where alteration has been extensive the rock has a granular texture.

Carbonates.—Both the minerals calcite and dolomite are present in the dolomite rock of the Davis region, but calcite is predominant at the Frost quarry. Everywhere in the altered dolomite, calcite is strongly replaced, both by the reaction silicates and the pegmatitic minerals. At places the calcite has been recrystallized to coarse segregations with garnet, diopside, clinozoisite, etc.

Reaction Silicates.—The character of the diopside, clinozoisite, phlogopite, and titanite, in the altered dolomite is similar to that described above for the fine-grained segregations in the pegmatite. They replace the calcite, but are themselves replaced by the pegmatitic minerals, with the exception of titanite, which is always euhedral. Clinozoisite and quartz form the symplektite described above.

Pegmatitic Minerals.—Microcline, plagioclase, and quartz have been introduced in large amounts into the dolomite. They replace the carbonates and contact silicates. The composition of the plagioclase is variable, as in the pegmatite, but the average NaO content is lower: varying from 55 per cent. ab to 85 per cent. ab, and averaging about 70 per cent.

Dolomite.—The dolomite even at some distance from the larger pegmatites shows considerable alteration (Fig. 1). Its texture and composition are the same as those described above. The dolomite outcrops along the Patapsco River are similarly altered. The rock to the southwest, off the limits of the map, is largely

unaltered, and consists of carbonates and phlogopite with a little accessory tremolite and quartz.

PEGMATITE OFFSHOOTS.

Several small quartz-albite dikes a few inches in width occur in the schist of the east wall of the quarry. They are cross-cutting and somewhat contorted.

A large fragment of dolomite on the dump shows parallel injections of pegmatite similar to a lit-par-lit gneiss. Abundant contact silicates are developed in both the pegmatite stringers and the intervening bands of dolomite. Some of the plagioclase in these stringers is very basic: 50 per cent. ab.

PARAGENESIS.

The Pegmatite.—The crystallization sequence for the minerals of the pegmatite is as follows:

Calcite,
Phlogopite, hornblende,
Titanite, apatite,
Clinozoisite,
Diopside,
Microcline,
Plagioclase,
Quartz, pyrrhotite,
Quartz-albite dikelets.

The Altered Dolomite.—The formation sequence of the minerals replacing the dolomite is as follows:

Original dolomite, calcite, and some phlogopite.
Phlogopite.
Titanite, apatite, and allanite.
Diopside, clinozoisite.
Garnet.
Microcline.
Plagioclase.
Quartz.

GRANITE DIKES.

Granite dikes from a few inches to three feet in width cut the Frost pegmatite. They are identical with those in the dolomite along the Patapsco River. They are fine-grained, nearly aplitic in texture, and have sharp boundaries with no contact phenomena. The essential constituents are microcline, oligoclase, and quartz. The accessory minerals are similar to those of the pegmatite: phlogopite, clinozoisite, actinolite, calcite, apatite, muscovite, and chlorite. They lack diopside, however.

The clinozoisite shows the same quartz intergrowths as in the pegmatite, and calcite, phlogopite and actinolite have been replaced by the feldspars and quartz. Fig. 7 shows a partially replaced relict of calcite in the granite, similar to those in the pegmatite.

ARLINGTON QUARRY IN DOLOMITE.

About 2000 feet northeast of the Frost quarry is a small opening for pegmatite wholly enclosed in dolomite. It is about 10 feet wide and 100 feet long along the strike, pinching out north and south, and is conformable to the enclosing dolomite—N. 65° E. 50° N.W. The essential minerals of the pegmatite are microcline and quartz, with considerable albite (95–100 per cent. ab). Biotite, muscovite, garnet, and tourmaline are accessory. The dike lacks the large diopside crystals developed at the Frost quarry.

Both the hanging wall and footwall of the dolomite are well exposed and are sharply limited against the pegmatite. The actual contact may be seen in thin section.

The contact minerals are the same as those at the Frost quarry, and develop the same textures. The plagioclase of the pegmatite is albite, that at the contact is oligoclase, while basic oligoclase and andesine are present in the dolomite a few inches from the contact.

COMPARISON WITH OTHER DEPOSITS.

With the exception of the Frost dike, the pegmatites of the Davis region are similar to the common types in Maryland and

elsewhere. The Frost body differs in the presence of segregations of dark minerals with coarse diopside.

The feldspar body near DeKalb Junction, New York, described by Shaub[12] bears many points of resemblance to the Frost dike. It occurs in crystalline limestone (Grenville) which is extensively altered around the deposit; feldspar is predominant over quartz; and it carries diopside, tremolite, phlogopite, titanite, pyrrhotite, apatite, smoky quartz, and even a little allanite. It differs in the absence of abundant plagioclase, in the somewhat larger size of the deposit, and in the presence of "horses" of altered limestone within the feldspar body. In its main features the author recognizes the same paragenetic sequence as is proposed for this deposit, *i.e.*, limestone—contact silicates—feldspar and quartz.

However, Shaub does not think the deposit is a simple pegmatitic injection, for the following three reasons: "(1) horses or residual masses of wall rock which at times completely cross the feldspar body; (2) a rock floor at places which consists of quartz and tremolite; (3) distinct and widespread gradation from the feldspar body, through the quartz-diopside border zone, into the country rock."[13] He thinks hydrothermal solutions emanating from a neighboring granite first altered the limestone with the production of the quartz-diopside rock, and later, becoming feldspathic, deposited the main tabular mass, presumably entering along the same channels as the first solutions, and choosing a position directly in the center of the altered limestone. On this basis he explains the inclusions of contact silicates and even some limestone within the feldspar mass as residual remnants of the replacement of the first-formed diopside-quartz rock.

MODE OF INTRODUCTION OF PEGMATITES.

In discussing the origin of the dikes of the Davis region a distinction must be made between the pegmatite itself and its hydrothermal facies. The latter depends on many factors, though chiefly on the proportion of volatile constituents carried by the

[12] Shaub, B. M., *op. cit.*

[13] Shaub, B. M., *op. cit.*, p. 88.

intruding mass, and on the nature of the enclosing rock, but hydrothermal activity in the dike walls is no necessary indication of a hydrothermal origin for the dike itself.

The smaller pegmatite and granite dikes in the Feeney quarry and along the river are normal intrusives, in that they have a dike-like form, sharp contacts with their walls, and are often contorted and pinching. They represent high-pressure injections of magma.

The Arlington and Moody dikes are similar in form and composition to these intrusions and are probably of the same origin.

For the Frost dike the following origin is proposed: An injection of soda-rich pegmatite magma occurred along the dolomite schist contact. In its passage upward it dislodged small fragments of the dolomite, and these by reaction with the pegmatite produced the segregations of contact minerals now found. Among the latter the fine-grained type, with some residual calcite, has not been as completely assimilated as the variety composed only of coarse diopside.

In the crystallization sequence, diopside and clinozoisite froze first, as shown by their euhedral outlines, and by the fact that they are often broken and separated. Later they were partially replaced, possibly due to some reaction relation. Finally the feldspar and quartz froze, and at the end the albite-quartz veins of the east wall and lit-par-lit injection into the dolomite were formed.

The reprecipitated calcite shown in Fig. 6 would suggest that the equation

$$\underset{\text{dolomite}}{CaMg(CO_3)_2} + 2\ SiO_2 \rightarrow \underset{\text{diopside}}{CaMg(SiO_3)_2} + 2\ CO_2$$

may have reached equilibrium at places, possibly due to the inability of carbon dioxide to escape. There are many pegmatites in the dolomite around Baltimore in which little or no reaction has occurred.

After the emplacement of the dike, hydrothermal solutions from the pegmatite effected extensive alteration in the dolomite. Whether all the alteration of the dolomite of the region is due to

the pegmatites alone or was aided from more deep-seated sources is not known, though the changes are more intense near the dikes.

That this was the origin of this body, rather than "waves" of hydrothermal solutions, which Shaub proposes for the New York deposit, is probable from the following considerations:

1. The structure of the body is similar to that of intrusive dikes. It is parallel to the strike and dip of the country rock as are the other pegmatites of the region, whereas hydrothermal deposits generally have irregular, stock-like outlines. The Arlington dike is completely in dolomite, and its form and sharp contacts are those of a dike, yet, with the exception of the coarse diopside, it is similar to the Frost pegmatite.

2. The dikes of the Davis region were under high pressure, and forced their way into the schists and gneisses. This is shown by the way many of them pinch, swell, and contort their walls. The lit-par-lit injections into the dolomite and the quartz-albite dikes at the Frost quarry indicate that the Frost pegmatite was under high pressure. Penetrating hydrothermal solutions could hardly produce such phenomena.

3. The composition of both the Frost body and the deposit near DeKalb, New York, is that of pegmatites, which are generally considered to be magmas, albeit aqueous ones. Potash feldspar, the predominant mineral in both deposits, is of minor occurrence in replacement processes.

4. The restriction of the coarse diopside segregations to the pegmatite at the Frost quarry could hardly be explained by Shaub's hypothesis. It necessitates the assumption that the later feldspathic solutions not only choose the coarse diopside rock as the locus of the continued hydrothermal activity, but that this locus was exactly co-extensive with the earlier diopside rock, extending to its very boundaries, but not extending into the dolomite. It might be questioned why the quartz-diopside shell around the New York deposit may not be due to reaction between the dolomite and pegmatite, rather than be the remnant of a former solid rock of quartz and diopside.

5. The broken and slightly separated crystals of diopside at

the Frost quarry are indications of a somewhat viscous mass, rather than of dilute, penetrating solutions.

6. Calcite remnants as shown in Fig. 7 are common in the granite, and if these bodies could assimilate carbonates the pegmatites could certainly do the same. Therefore the presence of minerals and textures in the Frost pegmatite which are due to its association with dolomite are not evidence against an intrusive origin for that pegmatite.

SUMMARY.

The Frost pegmatite near Davis, Howard County, Maryland, is similar in its main features to a feldspar deposit near DeKalb Junction, New York, described by B. M. Shaub. Both are associated with crystalline limestone and show extensive reactions with it, producing diopside rocks. Shaub proposes a hydrothermal origin for the New York deposit, solutions first developing a quartz-diopside rock, and later depositing feldspar by replacement within it. The evidence at the Maryland locality is that the body is an intrusive dike, forming diopside and other contact minerals by reaction and assimilation of the carbonate rock, as is attested by its structure, composition, and similarity to other intrusive granites and pegmatites nearby.

The writer wishes to express his thanks to Dr. Joseph T. Singewald, Jr., for suggestions and assistance in preparing this paper.

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AN UNDERGROUND PLACER CINNABAR DEPOSIT.[1]

JOHN T. LONSDALE.

THE Terlingua quicksilver district of southern Brewster County, Texas, is one that has attracted the interest of geologists for many years. Structural and general geologic conditions are of interest and in addition the district contains important quicksilver deposits from which a number of rare minerals have been described.

A number of papers, some of which are listed below, have been published describing the geology of the district and serving as summaries of the mining activity at the time of publication.[2] Recent activity in the district due to the high price of mercury has revealed an interesting occurrence of cinnabar, of a type not previously known in the district, though somewhat analogous deposits have been described in the past. The present paper describes the occurrence, which is thought to be of sufficient interest to warrant publication.

The Deposits.—The quicksilver deposits of the Terlingua district are epigenetic veins, chimneys, and irregular deposits in (for the most part) sedimentary rocks of Comanchean and Upper Cretaceous age. The mineralized area is some 15 miles long and five miles wide, extending in an east-west direction. In the western part of the district surface rocks are generally the hard limestones of the Comanchean but in the eastern part these rocks are several hundred feet beneath the surface, which is covered by

[1] Published with permission of the Bureau of Economic Geology, University of Texas.

[2] Hill, B. F., "The Terlingua Quicksilver Deposits, Brewster County, Texas," University of Texas Mineral Survey, Bull. 4, 1902. Phillips, W. B., "Quicksilver Deposits, Brewster County, Texas," ECON. GEOL., vol. 1, pp. 155–162, 1905. Turner, H. W. "The Terlingua Quicksilver Deposits," ECON. GEOL., vol. 1, pp. 265–281, 1905. Udden, J. A., "The Anticlinal Theory as applied to some quicksilver deposits," University of Texas, Bull. 1822, 1918.

the soft clays, flags, marls, and chalks of the Upper Cretaceous. The principal ore-bearing horizon has been the upper part of the Georgetown-Edwards beds, massive gray limestones lying beneath the impervious Del Rio clay. Cinnabar is also found in the overlying formations, frequently, however, beneath clays or other relatively impervious strata that have served to check the ore-bearing solutions in their upward movement, resulting in the precipitation of the ore minerals.

The upper part of the Georgetown-Edwards limestone is cavernous. Mines in the eastern part of the district working in this horizon at depth have encountered water following open channels in the rock. At the top of the formation such channels sometimes contain clay and other residual material impregnated with cinnabar, such deposits being known as *jaboncillo*.

The ore-bearing horizon of the Georgetown-Edwards outcrops in the western part of the district and this was the site of the original cinnabar discovery. Most of the early mining was done on veins in the limestone outcropping at the surface. Oxidation of these veins resulted in the formation of the rare oxychloride minerals first found in the district.[3] Present-day operations to some extent are still carried on in this part of the district but other operations are on the Georgetown-Edwards horizon beneath the surface in the eastern half of the district.

The Underground Placer Deposit.—The ore occurrence with which this paper is mainly concerned is in the southeast part of Section 38, Block G 12, in the western part of the district. Here the Georgetown-Edwards limestone outcrops and contains calcite veins bearing cinnabar. The veins have been worked intermittently for many years with some quicksilver production. Operations in the north part of the section are by the Waldron mines and those in the southeast part by W. F. Oaks, Jr., the latter operations being known as the Little 38 Mine. The exact location of the mine shaft is 1024 feet north and 1846 feet west of the southeast corner of the section.

[3] Hillebrand, W. F. and Schaller, W. T., "The Mercury Minerals from Terlingua, Texas," U. S. Geol. Surv. Bull. 409, 1909.

The ore deposit at Little 38 occupies an underground water channel which terminates at the surface in a sink hole depression filled with rubble. The ore had been followed vertically 320 feet, when examined, the shaft starting at the side of the sink hole. Fig. 1 shows the working to this depth. A recent communication

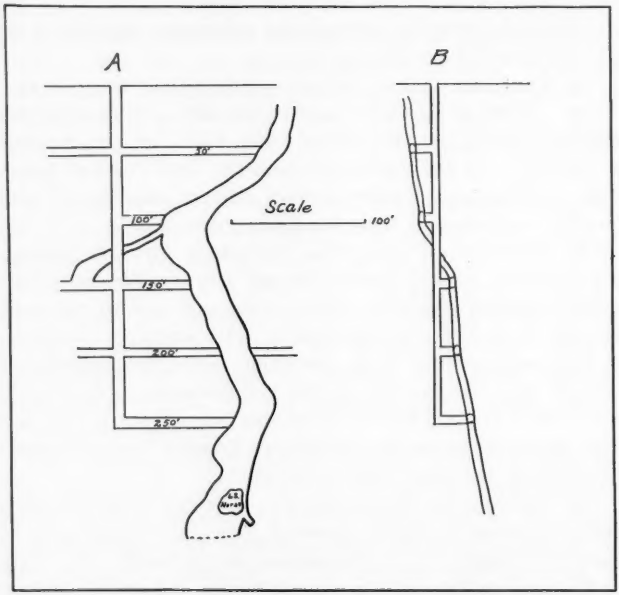

FIG. 1.—*A*, East-west section of workings at Little 38 mine to 320 feet. The profile of the solution channel from which ore has been taken is shown. *B*, North-south section of workings showing only profile of edge of channel and not its complete cross section and shape.

from Mr. Oaks states that the shaft is now down to 410 feet. The water channel is roughly vertical but departs from verticality, being crossed by the shaft on the 100-foot level and being 80 feet from it at other levels.

The channel is irregularly pipe-shaped, varying from 3 to 25

feet in longest cross section dimension, and irregularly contracts and expands in size. Its general shape is that of a number of pods on a string. Concave surfaces are numerous and there is little doubt that the opening has been formed by solution of the limestone. At the 50-foot level the channel intersects a pronounced joint in the limestone. Solution seems to have been guided downward by this joint. On either side of the solution channel the joint is filled with calcite vein material not carrying cinnabar.

The vertical chimney-like solution channel was filled from the surface to the deepest level yet penetrated by a red, finely laminated clay or silt, that contains fragments and cobbles of limestone and grains and occasional cobbles of cinnabar. The latter, jocularly called *gallos* by the Mexican miners, show effects of surface erosion. Bones of animals have also been recovered from the clay, and according to Mr. Oaks have been pronounced to be of Pleistocene age by officials of the Denver Museum. The clay shows numerous laminations, all horizontally arranged. These are of a fraction of an inch in width and usually cannot be traced completely across the clay mass.

At the 320-foot level, at the time the property was visited, an additional unusual feature was seen. The removal of the clay along the face of the opening revealed a small gallery some three feet in diameter branching off from the main channel. The upper two feet of this gallery was not filled with clay. The clay completely filled the gallery from that point downward to the junction with the main channel. The upper limit of clay in the gallery was therefore a plane surface some three feet in diameter and on it were unmistakable mud cracks. Latest information from the mines states that at the 410-foot level, the solution channel has divided into three branches each filled with the clay.

The entire filling of the solution channel constitutes cinnabar ore. The tenor is stated to be 0.67 Hg., which can be treated in most furnaces. A sample from the red silt clay readily pans cinnabar, and larger cobbles bring the grade of the ore up to the figure given above.

Origin of Deposit.—The origin of this unusual ore deposit is of course obvious. It is an underground alluvial or placer deposit. Numerous cinnabar-bearing veins are exposed in the immediate vicinity. Erosion of these has resulted in the filling of an open sink hole with clay containing limestone and cinnabar fragments. The size of the cavern and the tenor of the ore have been fairly uniform throughout the 320 feet in depth mined. Presumably the ore will continue downward as far as the open space exists. How far downward the open space exists is a question concerning which the writer does not care to hazard an opinion. It is known, however, that massive limestones extend several hundred feet below the bottom of the present opening at Little 38.

R. T. Walker [4] has recently discussed the deposition of ore in pre-existing limestone caves. He has described deposits of pipe-like form resulting from ascending ore-bearing solutions passing through caverns. The ore deposit at Little 38 superficially resembles such pipes. The complete absence of the usual types of mineralization, the eroded character of many of the ore fragments, and the presence of bones of animals show that it was not formed by ascending solutions even though the form is suggestive of such an origin.

A somewhat analogous deposit in the district was described by Turner.[5] This was the Tierra Lode, the eastern end of which practically coincides with the present deposit, which was traced for over 2500 feet on the surface in a northeast-southwest direction. The lode, through faulting, developed an open fissure along the middle of the vein. In places the fissure was filled with material washed from above, bones of mammals being among the material excavated. Cinnabar in this fissure comes largely from the adjoining walls, thus differing from the deposit at Little 38. Furthermore, the fissure was not completely filled and the deposit extended to no great depth.

Much of the surface debris in the western part of the district

[4] Walker, R. T., "Deposition of Ore in Pre-existing Limestone Caves," *Amer. Inst. Min. and Met. Eng.*, Tech. Pub. 154, 1928.

[5] Turner, H. W., *op. cit.*, p. 275.

contains cinnabar. Panning of fine detritus at the bases of slopes or in depressions rarely fails to reveal the cinnabar. At one place not far from Little 38, this surface material is being utilized for furnace ore. The presence of such material at the surface shows how readily a deposit of underground alluvial material rich in cinnabar could accumulate, given an open solution channel to receive it after rains.

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I. MAY CHROMITE CRYSTALLIZE LATE?[1]

EDWARD SAMPSON.

MUCH progress in petrology has been made by a clear recognition of the order of crystallization of minerals from a magma, but at times a belief in an immutable succession has blinded us in seeing the evidence of contradictory facts. In the study of silicate melts we know that physical conditions during cooling affect greatly the nature of the minerals which result, and that minor constituents play an important rôle in directing the course of crystallization. We have not yet fully realized the importance of the residual solutions, not only as to the kind of effects produced by them, but also as to the quantity of active solution which may exist after the formation of solid rock. The so-called accessory minerals have received their full share of discussion, particularly some of those which may form ores. Some would say that they have formed early; some that they are entirely introduced at a late stage; and others that they may form continuously from an early to a late stage, with most intense deposition at the beginning and end.

The writer wishes to raise the question as to the status of chromite. This mineral is perhaps the most generally accepted as representing the group supposed to crystallize completely at an early stage. The question at issue is: May a large part of the chromite of some ore deposits crystallize after the first formed silicates of host rock?

The question can not be answered conclusively, though an examination of the meager data at hand suggests an affirmative answer. Four lines of evidence which may be useful suggest themselves: (1), veins of chromite cutting rocks whose magmas may have furnished the chromite; (2), structural relations of chromite to other minerals, as revealed by the microscope; (3),

[1] Presented before the Society of Economic Geologists, December 30, 1927.

the association of chromite with minerals known to form at a late stage; (4), a study of the composition of the chromite as compared with the gross composition of the associated rock. Do different kinds of magma produce different kinds of chromite, and may there be a corresponding difference in structural relations

CHROMITE IN VEINS.

On the first subject, the occurrence of chromite in veins, there are enough observations to suggest that this manner of occurrence is more important than has been suspected, although in numerous descriptions of chromite deposits the term "bands" is used loosely and with such acceptance of an invariable origin by segregation that the descriptions have little value to one who would examine the evidence critically.

At the Wood's mine in Lancaster County, Pennsylvania, streaks of chromite are found, as illustrated in Fig. 1. The shape of the streak in the specimen illustrated seems to the present writer to indicate a replacement vein rather than a segregation. The evidence, though perhaps inconclusive, is strongly suggestive.

In his lengthy and careful description of the chromite deposits of New Caledonia, Glasser[2] mentions a number of vein-like bodies, but he does not distinguish clearly in most instances between the banding so commonly seen in chromite deposits, and true veins. However, he states that at the Belle-Pluie mine[3] a true vein was found ("c'est sous forme d'un filon net") about one meter wide, lying nearly vertical, and traceable with regularity for several hundred meters. The vein is composed of massive chromite and is in a country rock of more or less altered peridotite.

Some of the most illuminating occurrences which have been described are in the Selukwe region of Southern Rhodesia.[4] The principal chromite deposits of the region are associated with a

[2] Glasser, M. E., "Les richesses minerales de la Nouvelle-Caledonia, II, Le fer chrome." *Annales des Mines,* 10th Ser., Mem., vol. 5, pp. 69–110, 1904.

[3] *Op. cit.,* p. 84.

[4] Zeally, E. A. V., "The Geology of the Chromite Deposits of Selukwe, Rhodesia," *Trans. Geol. Soc. S. Africa,* vol. 17, 1914, pp. 60–74.

body of highly altered ultrabasic rock which for the most part is now a talc schist.

The chromite bodies are commonly distributed near the margin or on the actual edge of the Talc Schist formation. It often happens in such instances . . . that some chromite has found its way into the adjacent formation.[5]

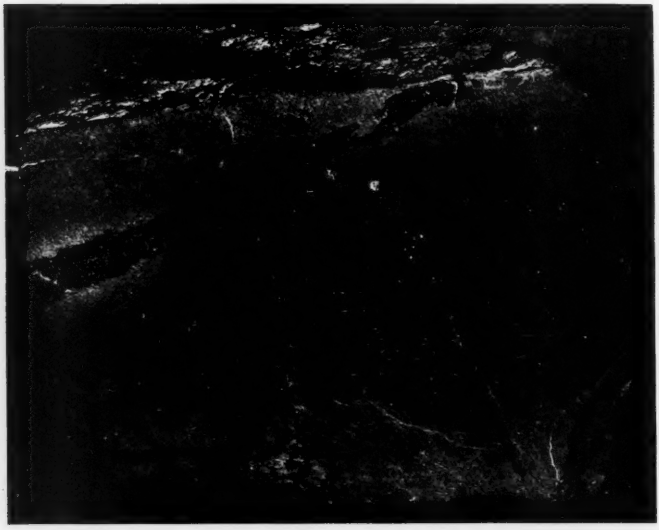

FIG. 1. Vein of chromite (dark) in serpentinized dunite. Wood's mine, Lancaster Co., Pa. Note intense serpentinization adjacent to vein. Length of specimen 4½ inches.

Near the Dunraven mine a massive body of chromite lies in conglomerate about 150 feet from the margin of the talc schist. It is about 150 feet long and three to four feet wide. "The conglomerate and grit matrix are pronouncedly green colored and contain chromite particles. Alongside this body are also remarkable streaks and narrow parallel bands of more or less closely

[5] *Op. cit.*, p. 65.

aggregated crystals and fragments of chromite intermixed with quartz grains of the grit in which it occurs and of grains and aggregates of chromite interstitial to brecciated pebble-like fragments of various rocks." This description seems to the present writer to indicate replacement. And again, near the "Chrome Mine" are several large bodies of chromite in conglomerate "at the margin of the talc schist." "The conglomerate at the junction with the chromite is colored green, and apparently brecciated. In it abundant isolated crystals of chromite occur interstitially to the pebbles, and a good deal of green (?) talcose material accompanies it." Replacement seems conclusive, and these offset

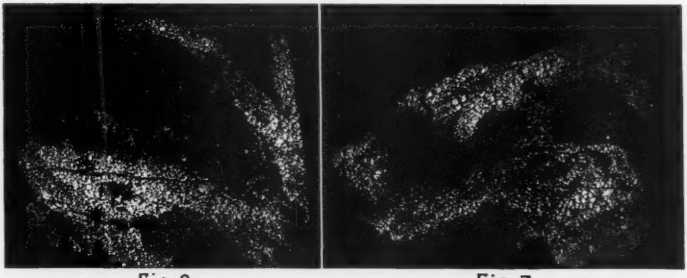

Fig. 2 Fig. 3

FIG. 2. Vein-like chromite (light) in serpentinized dunite. Kraubat, Styria. Photograph taken by reflected light. Length of specimen 4½ inches. × 50.

FIG. 3. Opposite side of same specimen as Fig. 2.

deposits are not possibly to be ascribed to an early crystalline differentiate which has been squeezed out, but rather to a late formed liquid which deposited talc and chromite metasomatically.

Another instance of the late origin of chromite came to the writer's attention in studying some specimens from Kraubat, Styria, in the collections of Princeton University. The most important of these specimens is illustrated in Figs. 2 and 3. In this specimen clouds of small chromite crystals follow a reticulated pattern suggesting strongly a secondary origin. It may

further be observed that the chromite-free portion is dunite partly altered to serpentine, but that in the chromite-bearing portion serpentinization is complete. The boundaries between these portions are gradational.

It should be noted, however, that Ryba,[6] who studied the Kraubat deposits in detail, ascribes to all the chromite an origin by crystallization prior to the crystallization of olivine. Although the present writer would not go so far as to say that all the chromite formed at a late stage, he believes that Ryba's argument is of particular application only to the accessory chromite disseminated rather uniformly through the body of the rock, and

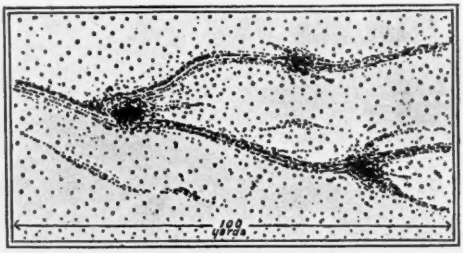

FIG. 4. Stringers of chromite in serpentine. Island of Unst, Scotland. From figure in paper by C. S. Hitchen, *Mining Mag.*, vol. 40, p. 23, 1929.

that at least in the specimen illustrated in the present paper the chromite was introduced metasomatically. Since this paper was presented before the Society, Hitchen has described[7] the chromite deposits of Unst, the northernmost of the Shetland Islands. Chromite is contained in a serpentinized dunite.

The commercially workable deposits of chromite fall into two classes, namely large local segregations, or "pots," and deposits of a vein-like character which wind tortuously through the serpentine, apparently without relation to anything as regards direction. . . . The smaller vein-like

[6] Ryba, Franz, "Beitrag zur Genesis der Chromeisenerz lagerstätte bei Kraubat in Obersteiermark," *Zeit. f. prak. Geol.*, pp. 337–341, 1900.

[7] Hitchen, C. Stansfield, "Unst and its Chromite Deposits," *Mining Mag.*, vol. 40, pp. 18–24, 1929.

occurrences, already alluded to, are frequently observed in the hillsides north of Baltasound, where trials have been made upon them. The ore exposed in these trials is of the banded variety and stringers of it wind through the serpentine and occasionally several of these fuse to form a small nucleus. This latter mode of occurrence is illustrated in Fig. 4, and doubtless represents the chromite in the act of segregating, a process which was in this case cut short by the consolidation of the magma. As far as I could gather, it was found unprofitable to work such ore under the prevailing conditions.

Hitchen's figure suggests veining to the present author. A process whereby segregation could produce such branching seems hard to picture; on the other hand, veining, with replacement, commonly produces such forms.

STRUCTURAL RELATIONS TO OTHER MINERALS.

The second line of evidence, structural relations of chromite grains, has furnished a little evidence and can probably furnish much more. To be sure, Diller showed by this method that at Castle Crag mine, Shasta County, California, chromite clearly crsytallized before olivine,[8] and the present author would not question either Diller's conclusion or its wide application.

Wagner has recently given a very clear case of a different state of affairs.[9] Near the base of the Bushveld Igneous Complex of the Transvaal a chromite-rich rock, chromitite, is found. The rock is composed of bronzite, chromite, and basic plagioclase. Chromitite and bronzite seem to stand in a complementary relation to anorthosite, all of which have differentiated from a parent norite magma. In the chromitite richest in chromite, Wagner states the order of crystallization to be chromite, bronzite, plagioclase. The most significant feature of the chromitite as bearing on the subject in hand is the relation of the chromite to the bronzite in the leaner portions of the chromitite. Two illustrations from Wagner's paper are reproduced in Figs. 5 and 6. The bronzite occurs in large crystals over a centimeter in diameter,

[8] Diller, J. S., "Chromite in the Klamath Mountains, California and Oregon," U. S. Geol. Surv. Bull. 725, pp. 1–35, 1921.

[9] Wagner, P. A., "The Chromite of the Bushveld Igneous Complex," *So. African Jour. Sci.*, vol. 20, pp. 223–236, 1923.

but the chromite crystals are generally but a fraction of a millimeter across. These chromite crystals occur interstitial to the bronzite and included poikalitically in the outer part of the bronzite, the chromite grains tending to become coarser in proportion to the distance out from the center. Some basic plagioclase is associated with the chromite.

FIG. 5. Chromite interstitial to bronzite. Lydenburg district, Transvaal. From photograph by A. L. Hall, published by P. A. Wagner as Plate 4, Fig. 2, *So. African Jour. Sci.*, vol. 20, 1923. ×9.3.

Wagner concludes that "we have evidently to do with a case where the first mineral to crytallize was that which was in excess of certain definite proportions,[10] and further states:[11]

It is generally assumed that the chromitite and associated igneous rocks are of the *accumulative type;* or, in other words, that they owe their origin

[10] *Op. cit.*, p. 229.
[11] *Op. cit.*, p. 232.

to the collection under the influence of gravity of early-formed crystals that separated from the parent norite magma. The chromite seams and lenses are thus to be regarded merely as local concentrations of the same type of chromite as is so widely disseminated in more or less isolated crystals in the ultrabasic rocks of the Bushveld Complex. On the theory of origin briefly outlined, the pseudo-porphyritic structure of the normal chromitite can only be explained on the supposition that the phenocrysts

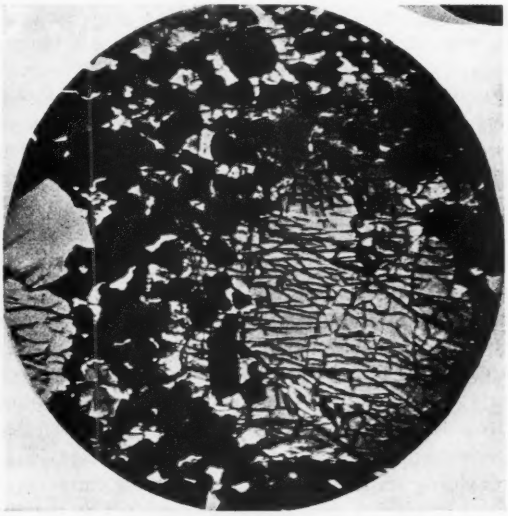

FIG. 6. Chromite crystals included in and interstitial to bronzite. Twinned grain of plagioclase on left. From photograph by P. A. Wagner, Plate 4, Fig. 1, *So. African Jour. Sci.*, vol. 20, 1923. × 20.2.

of bronzite with their small chromite enclosures settled simultaneously with the larger chromite crystals, and thus became imbedded in accumulations of such crystals.

To the present writer this manner of origin seems inconsistent with the recorded arrangement of the minerals, and the lean chromitite would seem to be explained better by the chromite being in a residual solution. Final crystallization would have

taken place *in situ*, and in this manner the gradation in size of the chromite crystals and the association of chromite with plagioclase seem much more rational.

MINERAL ASSOCIATION

The third class of evidence, the association of chromite with secondary minerals, is dealt with at length in the following paper by C. S. Ross, which gives detailed evidence regarding a classic locality.

In passing, attention may be directed to the fact that prior to the work of Vogt in 1894,[12] the common association of chromite with serpentinized peridotite was recognized, and although the geologists of that time ascribed the source of the chromium to the serpentinized silicates, there may be much to reconcile their field observations with the more modern view that the solutions which brought about serpentinization introduced chromite. This is in accord with Benson's [13] well substantiated conclusion that serpentinization of ultrabasic rocks is due to their stewing in their own juice.

In both of the hand specimens illustrated in this paper chromite is closely associated with the most complete serpentinization. That from Kraubat, Styria (Figs. 2 and 3) has been described. The specimen from the Wood's mine, Pennsylvania (Fig. 1) illustrates clearly serpentinization accompanying chromite. In the illustration it appears as a light halo surrounding the chromite. Away from the chromite residual olivine is abundant, but serpentinization increases to completion as the chromite is approached. The alternative explanation of the localization of late serpentine by an early segregated band of chromite seems less probable than contemporaneity, in particular when the markedly veinlike outline of the chromite is taken into consideration.

When discussing association of chromite with hydrothermal

[12] Vogt, J. H. L., "Beiträge zur genetischen classification der durch magmatische Differentiationprocesse und durch Pneumatolyse entstanden erzvorkommen," *Zeit. f. Prak. Geol.*, pp. 384–393, 1894.

[13] Benson, W. N., "The Origin of Serpentine, a Historical and Comparative Study," *Am. Jour. Sci.*, 4th Ser., vol. 46, pp. 693–731, 1918.

minerals, attention should be called again to the associated silicate which, together with chromite, replaces the matrix of a conglomerate near the "Chrome Mine" in the Selukwe district, as previously mentioned.

COMPOSITION OF CHROMITE.

The evidence which might be gained from the relation, if any, of the composition of the chromite to the associated primary silicates has not been investigated, although Gil [14] has suggested its possibilities. The composition of chromite is very variable, and it is to be expected that chromite formed by segregation should bear a relation to the composition of the associated primary silicates, at least one of which, olivine, is also of variable composition. This might possibly serve as a means of distinguishing between primary and secondary chromite.

CONCLUSION.

In conclusion, the writer feels that at present we are justified in believing that, although much chromite may crystallize at a very early stage, a substantial amount of the constituents of the mineral passes into a residual solution and even into a highly aqueous solution capable of considerable migration.

PRINCETON UNIVERSITY,
PRINCETON, N. J.

II. IS CHROMITE ALWAYS A MAGMATIC SEGREGATION PRODUCT? [1]

CLARENCE S. ROSS.

CHROMITE seems to be always classed as a magmatic mineral; in fact, it is often referred to as a typical example of a mineral that has been formed by magmatic segregation. This is probably

[14] Gill, A. C., "Chromite in the Kenai Peninsula, Alaska," U. S. Geol. Surv. Bull., 742, 1922.

[1] Presented before the Society of Economic Geologists, December 30, 1927. Published by permission of the Director of the U. S. Geological Survey.

true of many occurrences of chromite, but some of those in North Carolina present certain features that raise the question as to whether chromite is always formed in that way.

The North Carolina dunite bodies, many of which carry chromite, are little altered and therefore present unusually good opportunities for the study of mineral relations. The physical relationships of chromite to dunite and the chemical distribution of the chromium in the silicate minerals indicate that at least a part of the chromium is later than the dunite, and suggest that it may be hydrothermal in origin.

The chromite body that has been studied most is part of the Webster dunite area. This has the form of a ring dike with a major axis six and one half, and a minor axis three and one half miles in diameter. The dunite is dominantly olivine, or olivine and its alteration product, serpentine, and is cut by a large mass of Websterite—a rock composed of orthorhombic and monoclinic pyroxene (bronzite and green diopside). The width of the ring varies from a few feet to nearly one half mile. During the war chromite was mined from the broader part of the dunite, a short distance southeast of Webster.

Chromite is sparsely disseminated through most of the dunite, but the greatest concentration seems to be along the southeastern border. Here the chromite occurs in bands that are continuous for many feet, and in occasional boulder-like masses inclosed in dunite. The bands are commonly only a fraction of an inch in width, others about one half inch and only a few are 4 inches wide. Most of the chromite grains are anhedral or subhedral, but a few are fairly perfect octahedrons.

Zones of anthophyllite and talc surround the Webster dunite body, and indeed this is a conspicuous characteristic of most, if not all, the North Carolina dunite bodies. Within the dunite are sparsely disseminated grains of actinolite, kammererite, talc, diallage, and locally there are many small veins cutting the dunite that contain anthophyllite, tremolite, biotite, talc, chlorite, vermiculite, serpentine and kammererite. Most of these disseminated and vein minerals are typical of mineral assemblages that have been formed by hydrothermal processes.

The distribution of chromium in some of the minerals of the Webster region is shown by the following analyses:

ANALYSES OF OLIVINE AND ASSOCIATED MINERALS OF THE DUNITE, WEBSTER, NO. CAROLINA.

By Forrest A. Gonyer.[2] Corrected for Cr_2O_3 by J. J. Fahey, U. S. Geological Survey.

	(1) Olivine.	(2) Serpentine.	(3) Bronzite.	(4) Green Diopside.	(5) Kammererite.	(6) Green Tremolite.
SiO_2	39.14	35.56	53.69	52.34	30.78	54.36
Al_2O_3	.52	2.46	2.88	2.04	12.82	2.90
Fe_2O_3	2.38	4.57*	.34	.96	1.56	0.45*
Cr_2O_3	none	0.05*	.36	.46	3.54	0.37*
FeO	6.04	2.02	8.42	2.88	2.91	2.02
MgO	51.64	39.88	31.94	17.56	35.54	24.74
NiO	.34	.22	....	....	.22	0.20
CaO	....	.10	2.11	23.96	.14	12.32
MnO	....	....	.22	.09	....	0.04
H_2O-110°	....	.88	....	....	.18	....
H_2O-110°	....	....	....	....	12.48	1.82
	100.14	100.78	99.96	100.29	100.17	99.22

The analyses of olivine (see analysis 1) and qualitative tests of the bronzite by J. J. Fahey, chemist of the U. S. Geological Survey, show that the original pyrogenic silicate minerals of the dunite are chromium-free, but serpentine (analysis 2) derived from olivine carries small amounts of chromium. The kammererite (analysis 5) and green tremolite (analysis 6) are secondary hydrothermal minerals sparsely disseminated through the dunite that contains small but essential amounts of chromium, and the kammererite, green tremolite and vermiculite of the small veinlets are also chromium-bearing. The amount of chromium in the silicate minerals is not large, but they are so abundant that the total amount must be very great and constitute a large proportion of the chromium in the Webster locality. Thus it is evident that the earlier pyrogenic silicates of the dunite, the minerals that are most closely associated with the chromite, contain no chromium while the websterite mass and some of the secondary

[2] Ross, Clarence S., Shannon, Earl V., and Gonyer, Forrest A.; The Origin of Nickel Silicates at Webster, North Carolina, ECON. GEOL., vol. 23, pp. 528–552, 1928.

hydrothermal minerals do contain it. The question arises as to the source of the chromium in these hydrothermal minerals; did the hydrothermal solutions originally contain chromium or is it derived entirely from reactions between these solutions and earlier chromite?

The relationship between dunite and websterite is not clear but the absence of chromium in the silicates of the dunite and its presence in those of the websterite, indicate that there were two distinct magmas—one chromium free and the other chromium bearing—or extensive post-magmatic reactions with the introduction of chromium. In neither case is it probable that the chromium was derived from previously crystallized chromite of the dunite. If the chromite crystallized directly from the dunite magma, it is hard to explain why the silicates associated with it are chromium-free, since the analyses of the websterite show that the bronzite is capable of containing chromium, and even olivine may take up small amounts of the R_2O_3 bases.

Pratt and Lewis [3] have pointed out that the dunites contain sharply defined shear planes so that the dunite locally resembles a bedded rock. They say:

> A highly laminated structure is universally developed in the region around Webster; and it is not unnatural that it should have been regarded as a thin bedded olivine sandstone. The lamination is parallel to that of the inclosing gneisses . . . the examination of thin sections under the microscope shows these laminated varieties to consist of an alternation of layers of pulverized olivine with others of typical, massive granular structure. This structure then is believed to be intelligible only on the supposition that the rock was originally a structureless granular mass in which lamination has been induced dynamically.

Chromite has been mined southeast of Webster from a series of pits distributed along one of these shear zones in the dunite, and the chromite occurs as thin lenses that are concordant with the shear planes which dip nearly west at an angle of 60° to 70°. Thus the physical relations of chromite to dunite appear to be controlled by shear zones in the dunite, and it seems almost neces-

[3] Pratt, Joseph Hyde, and Lewis, J. Volney, "Corundum and Peridotites of Western North Carolina," No. Carolina Geol. Survey, vol. 1, pp. 92 and 140, 1905.

sary to conclude that the crystallization and shearing of the dunite preceded the formation of chromite. This relation would preclude the possibility of the formation of chromite by magmatic segregation.

Some of the chromite in the larger lenses in the shear planes (up to one-half inch across) are associated with the hydrothermal minerals actinolite and kammererite, and a few contain iron-rich carbonates. Bowen [4] has reported talc veinlets that contain large bleb-like masses of chromite entirely surrounded by talc.

In conclusion it may be said that the Webster, North Carolina, dunite shows certain relations that are difficult to explain on the assumption that chromite is an early pyrogenic mineral. The silicates of the normal dunite contain no chromium but the websterite and later hydrothermal minerals in the dunite do. It is, therefore, evident that chromium was present in the material that crystallized into the websterite and possibly in hydrothermal solutions. The relation of the chromite suggests very strongly that at least a part of it is later than the surrounding silicates; it occurs most abundantly in shear planes in the dunite, and it forms vein-like masses where it is associated with hydrothermal minerals that are themselves chromium-bearing. These relations seem to be best explained if at least a part of the chromium has been deposited by hydrothermal solutions.

III. *DISCUSSION* [1]

Edward Sampson: May chromite crystallize late?

C. S. Ross: Is chromite always a magmatic segregation product?

I was much interested in these two papers on chromite and the conclusions arrived at by the authors. In 1916 appeared the important monograph by Tolman and Rogers on the magmatic sulphide ores. They showed that the ore minerals in magmatic segregations of sulphide ores were not the first minerals to separate out and crystallize from the magma; but that, through the agency of mineralizers, these constituents of the magma were rendered

[4] Personal communication.

[1] Society of Economic Geologists, December, 1927.

more mobile and kept in solution until after the rock-forming minerals had solidified, and that ore deposition took place through the introduction of these constituents into the already solidified silicate minerals and at their expense. The oxidic ores associated in small amounts with the sulphidic ores in these deposits showed the same relationships to the rock-forming silicates, though they preceded the sulphides in order of deposition. The studies of Tolman and Rogers showed that magmatic segregations of sulphidic ores do not conform to the old petrographic conception that the ore minerals are the earliest to solidify from the magma because of their high melting points, in the manner of the separation of the accessory ore minerals of igneous rocks, but that mineralizers have played an important rôle in delaying the crystallization and localizing the deposition of those minerals.

Shortly after, in 1917, I discussed the magmatic segregations of the oxidic ores from the same standpoint in a paper in the *Mining and Scientific Press* entitled "Magmatic Segregation and Ore Genesis." A review of the literature on the oxidic magmatic segregations showed only an occasional recognition of the ore minerals as later than the rock-forming silicates, and this was usually explained away as a departure from the prevailing rule that the iron ores belong to the earliest minerals to separate. A few years before, I had made a comprehensive study of the titaniferous iron ores of the United States. The paragenetic relations of the minerals in those ores were in harmony with the relations set forth by Tolman and Rogers. If such segregations were formed without the intervention of mineralizers, the deposit at Iron Mountain, Wyoming, ought to afford an example. The ore body is an almost pure mass of titaniferous magnetite cutting the anorthosite country rock as a well-defined dike. Yet olivine crystals, which are abundant locally in the ore, are rounded and embayed without the formation of reaction silicates. At Grape Creek, Colorado, the introduction of ore has been accompanied by alteration of the feldspar of the country rock so that the magnetite is separated from it by a band of hornblende, indicating considerable activity of mineralizers.

Even more pronounced is the evidence of the agency of mineralizers in the formation of the magmatic segregations of non-titaniferous iron ores. A striking example had only a short time before come to my attention on a visit in 1915 to the Tofo deposit of the Bethlehem Steel Company north of Coquimbo, Chile. This consists of a large mass of comparatively pure magnetite forming the top of a hill on the east side of the coast range within a large area of gabbro. The igneous mass has undergone considerable differentiation, and various rock types are represented in the vicinity of the ore body ranging from highly feldspathic to almost pure ferromagnesian silicate rocks, some of which occur as dikes. Though the broader relations of the ore body are those of a magmatic segregation, there are features suggestive of pneumatolysis. Numerous stringers of magnetite extend into the country rock with a thickness no greater than that of a knife blade, traversing it in such a way as to preclude the entrance of molten oxides. Their material must have come in under the conditions of high liquidity and lower temperature possible only through the presence of an abundance of mineralizers. Much evidence along the same lines, nearer at hand, is afforded by the literature on the magnetic iron ores of magmatic origin associated with granular igneous rocks in the eastern United States.

Processes in nature representing stages of a sequence are usually continuous and not separated by an hiatus. If mineralizers played an important part in the formation of deposits of magmatic sulphides and of iron ores, both titaniferous and non-titaniferous, it was to be expected that chrome deposits would display the same phenomena. Accordingly, I reviewed at that time the literature on chrome ores from this standpoint, but found it of little service, as the descriptions of the ores were not critical and the deposits had been described in accordance with the current belief concerning the nature of magmatic segregations. Modern petrographic and metallographic studies of the paragenetic relations of the constituent minerals had not been made. Recognizing the desirability of such a study of the chrome ores, I was awaiting an opportunity to undertake it. Several months ago, not knowing that Messrs.

Sampson and Ross had commenced the work, I started Mr. Lloyd W. Fisher on a comprehensive study of the chrome ores with this question as one of its main purposes. Mr. Fisher's investigation has not yet progressed far enough to throw light on the problem, but the papers by Messrs. Sampson and Ross indicate that the chrome ores line up with the other oxidic ores in giving evidence of the activity of mineralizers in their deposition and that they do not represent solely a direct segregation of the first product of crystallization from a molten magma.

It is worth while pointing out in this connection that these newer conceptions growing out of the paragenetic relations of the minerals of magmatic segregations conform to views long held by the French school of economic geologists, of which the leading modern exponent has been De Launay. In his *Gites Mineraux et Metalliferes,* published in 1913, De Launay gives as the first three divisions of his genetic classification of ore deposits (which embrace the genetic range of the deposits I am discussing) the following:

1. Deposits of included mineral.
2. Deposits by segregation.
3. Peripheral sulphide segregations.

He says: "Deposits of inclusions are those where a useful mineral occurs in an igneous rock in the same relation as the other constituent elements." This division includes only native metals and oxides present as normal accessory constituents of an igneous rock without the intervention of mineralizers. From the standpoint of economic geology, the division is of theoretical interest rather than of practical importance. In the formation of the segregation deposits he thinks water and probably other mineralizers played a part, though he considers them formed in a medium poor in mineralizers. The ores of these deposits are also native metals and oxides. The peripheral sulphide segregations, De Launay says, represent a type in which mineralizers are still more active and abundant. He considers them so distinct from the true segregations that he says they are parent to contact metamorphic deposits which are formed when the wallrock is limestone.

The essential rôle of mineralizers in ore deposition, even in the case of deposits of most intimate magmatic relationships, is then established by the paragenesis of the minerals in those deposits. Though the evidence is most pronounced in the magmatic sulphides because of the important part played by the mineralizers in those deposits, it is no less clear in the deposits of the oxidic ores, even though in general the mineralizers appear not to have been so abundant in the latter and there is often a juxtaposition of early ore minerals and late hydrothermally or pneumatolytically introduced ore minerals. The evidence points strongly to the conclusions that when ore minerals separate from a magma as the earliest constituents to crystallize, they are likely to constitute but accessory minerals of the host rock; and that, in those cases in which the metallic constituents of the magma have been locally concentrated to form masses of sulphidic and oxidic ores of economic importance, mineralizers have been an effective agent in segregating those metals into the residual magma fluid. Or, expressed in other words, ore deposits have generally resulted only when mineralizers have retarded the early crystallization of the ore minerals, thereby facilitating their retention by the residual magma fluid and their concentration within it. The highly mobile and liquid metalliferous magmatic extracts had the power of penetrating the rock-forming silicates which had in the meantime crystallized, and replacing them locally with the ore minerals, giving rise to ore bodies of such size and richness as to make workable deposits of the metals.

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BALTIMORE, MD.

EDITORIAL

SOME REMARKS ON REVIEWS AND CRITICISMS.

A FEW days ago I took up a recent volume of reviews in *Neues Jahrbuch* which happened to deal with economic geology. Many of these abstracts were from the pen of Dr. Schneiderhöhn. I became deeply interested and read on with much profit, also some entertainment and amusement. Needless to say the abstracts are excellent. They are not only lists of contents of the original papers but contain in addition individual comments of the abstractor which are like a dash of paprika making a dish palatable. One of the first reviews deals with the report of the committee on processes of ore deposition appointed by the National Research Council of this country. The reviewer is evidently favorably impressed with the general plan but wishes that it could have been made broader, including foreign problems of the same kind, and hopes that some kind of a broader international commission might be created. He realizes that this is scarcely feasible at the present moment but suggests a similar coöperation on the part of German, Scandinavian, Swiss and Russian societies. Why the other nations of Europe have been left out is not explained but one seems to perceive the specters of nationalism raise their heads. The problems outlined for research seem to the reviewer of the "allerverschiedensten Art." This, I admit most cheerfully, is true but the fact seems to be that such broader treatments have become necessary in this country if we would emerge from the mass of detailed descriptions and formulate general laws. I observe just such a plan has been taken up recently by Dr. W. H. Emmons who seems to have succeeded in summing up the characteristics and inter-relations of the Mississippi Valley lead and zinc deposits, and by Dr. H. G. Ferguson in discussing broadly the numerous mining districts of

Nevada, both in recent numbers of ECONOMIC GEOLOGY. It was suggested in the paper by the committee that many terms are carelessly used and need sharper definition. Such are pneumatolysis, replacement, diffusion, colloidal processes, deuteric processes, etc. To Dr. Schneiderhöhn further definitions are entirely unnecessary: the majority of these terms are already perfectly clear and sharply defined; the only trouble is with the various authors (particularly American) who do not understand that everything between the nicely indicated lines t_1 and t_2 in the composition-pressure diagram is "pneumatolytic" and that everything below that space is "hydrothermal." Just the same I defy Dr. Schneiderhöhn, or Dr. Niggli, or anyone else to produce an approximately workable definition of the word "pneumatolytic" with application to concrete examples. The tendency of most American writers to restrict or remove the term "pneumatolytic" is worrying Dr. Schneiderhöhn greatly, as may be seen in a subsequent abstract of the paper of C. S. Ross on "Physico-Chemical Factors, etc." (ECON. GEOL., 1928). The reviewer advances a strong appeal to retain the term (1) because of its usefulness, (2) because of Bunsen (who originated it), and (3) because European scientific men have introduced it and therefore have "priority." Ross says: "For these reasons 'pneumatolytic' and its derivatives have lost all definite meanings, and the term 'gas phase' and 'gas phase reactions' will be used exclusively in this paper to describe processes of this type." With this conclusion I heartily agree.

However, Dr. Schneiderhöhn was not always so keen on pneumatolysis, for I observe that in a classification published by him in 1919 (Die Grundlagen einer Genetischen Systematik der Minerallagerstätten, Senckenbergiana, 1, No. 6) no place has been given to pneumatolytic deposits.

Errors and omissions seem to be inseparable from scientific work. This, of course, is quite natural. One way to avoid them might be to keep one's papers from publication in order to make them perfect and to issue them at the close of one's life in beautifully exact form. Indeed some men are inclined to follow this

prescription, which among other things would have the advantage that the author might not live to see the residual errors pointed out. But obviously such a proceeding would not accelerate scientific progress. Many of us, who have written on various subjects ranging from Montana to Patagonia with excursions elsewhere, have been obliged to stand the attacks of criticism, and—aside from personal feelings—this is good for our souls. Even Dr. Schneiderhöhn knows how it feels. One of the favorite indoor sports of critics is to point out the lack of knowledge of earlier literature shown by their victims. Europeans frequently accuse us of this and perhaps we are guilty; anyway cases of the opposite kind have been known. Sometimes, however, the criticisms are unjust and the worm feels obliged to turn and remonstrate. We are not really as bad as Dr. Schneiderhöhn thinks we are. Dr. A. R. Whitman, writing on diffusion, is accused of overlooking the important work of Liesegang. I am sure he knows all about it, only he was describing certain definite experiments and it scarcely seemed necessary to widen the description into a general review of literature. A paper by Lindgren and Creveling on the ores of Potosi (ECON. GEOL., 1928) is reviewed—very excellently indeed—but the statement is made that the important work of Gustav Steinmann was not known to the authors. Indeed they were well acquainted with it. As a matter of fact the senior author quoted it and used it extensively in a paper on gold and silver deposits in North and South America (*Am. Inst. Min. Eng.*, 1916), but it did not seem necessary to refer to it in a piece of work specifically describing the Potosi ores; and Steinmann's borrowed section from Potosi was not accurate enough to be introduced. The next point of attack is on Dr. Newhouse, who happens to be closely associated with me in the Massachusetts Institute of Technology. His paper on the time sequence of hypogene ore mineralization (ECON. GEOL., 1928) is well reviewed, but the author is severely criticized because he apparently was entirely ignorant of Dr. Niggli's work on "Versuch einer Klassifikation der Magmatischen Lagerstätten im weiteren Sinne." Now, really and truly, we are not guilty,

because this important paper has for many years been diligently studied in this Department; a translation of it in English has been made by Dr. Boydell, and I myself have made liberal quotations from it in the last edition of a book entitled "Mineral Deposits." But again there seemed to exist no necessity for its elaborate discussion in a paper that dealt with the time sequence of minerals, with the replacements in ores by one mineral after the other, in a well-defined order which as far as I can ascertain has been discussed in detail neither by Dr. Schneiderhöhn nor by Dr. Niggli. Of course, we do not claim to have discovered paragenesis, but we have tried to reduce it to order and to find an explanation for it that goes further than the general principles of rock differentiation. I notice a recent very suggestive paper by B. S. Butler and W. S. Burbank (*Trans. Am. Inst. M. and M. Eng.*, 1929) which deals with the same subject. They have not found it necessary to discuss the whole of the earlier literature on differentiation.

I hope this editorial will not be looked upon as a matter of polemics or carping criticism. As I said at the outset, I have enjoyed the abstracts by Dr. Schneiderhöhn very much indeed, and I hope he will write many more of them.

WALDEMAR LINDGREN.

DISCUSSION AND INFORMAL COMMUNICATIONS

THE MAGNESITE DEPOSITS OF EUBŒA, GREECE.

Sir: It may interest your readers to learn of some observations, which the writer believes to be new, on the magnesite deposits of Eubœa, which may correlate with the work done by Boydell,[1] and also serve as a confirmation of Bateman's [2] theory on angular inclusions in replacement deposits.

The most important deposits and mines of Grecian magnesite are situated on the island of Eubœa, which is separated from the mainland by the Atlantic Canal. On this island there is an east-west belt of serpentine from 8 to 10 miles wide and about 18 miles long which cuts across beds of Cretaceous limestone. The continuation of this belt may be traced on small islands in the Aegean Sea and even on the mainland in Asia Minor.

Another important serpentine belt can be traced from the eastern part of Salonica to the site of ancient Acanthos, and from it is quarried magnesite equal to that of Eubœa, but near Salonica it is softer in quality.

The Eubœan magnesite occurs commonly in the form of lenses which strike E.–W., NE.–SW., and NW.–SE. Many of them are of large size; for example, the Archangelo lens is 130 feet wide at the outcrop and extends 1400 feet in length, with a northwest dip; the Mandoudi deposit, which strikes NW.–SE., is 160 feet wide at the surface and one-half mile long. The interesting deposit of Voriarema at Limni, which strikes east-west across shale, has an abnormally high percentage of lime—12.4 per cent. in the calcined material.

[1] Boydell, H. C., "The Magnesite Deposits of Eubœa, Greece," ECON. GEOL., vol. 16, pp. 507–523, 1921.

[2] Bateman, A. M., "Angular Inclusions and Replacement Deposits," ECON. GEOL., vol. 19, pp. 504–520, 1924.

The commercial magnesite of Eubœa does not usually exceed 500 feet in depth—approximately the ground water line. In addition to the large deposits, veinlets of various sizes cut the serpentine in all directions. The deposits as a rule have footwalls of a peculiar soft serpentine, which indicate to the prospector the approach to magnesite; the hanging wall often shows well defined slickensides. Faulting is not uncommon. In horizontal section (Fig. 1) the deposits pinch and swell.

Small bodies of serpentine, usually hard, are scattered through the magnesite and in some places are abundant. Where the serpentine has not been completely altered to magnesite, it may contain wollastonite and calcite.

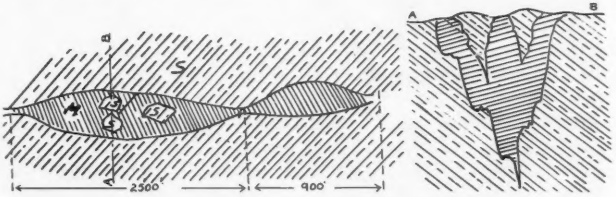

FIG. 1. Mandudy deposit, horizontal section. *S*, serpentine; *M*, magnesite. Right, vertical section.

The magnesite is usually white, but in places it is tinged with iron oxide. Lime and silica are unevenly distributed throughcut, and as the proportion of either increases, that of the other diminishes. There seems to be less lime in the narrower veins.

An interesting deposit on the mainland is Skender-Aga, where the veins are too small to be worked profitably, but one of them is unique in that it occurs along a limestone-serpentine contact, and some of the limestone beneath the magnesite is altered to dolomite, which the writer believes was caused by magnesium carbonate solutions penetrating the limestone and replacing the carbonate of lime. The portion of the latter which was removed was deposited in cracks in the limestone nearby. Wollastonite is found here and there along the limestone contact.

A curious feature of the Xeropotamo deposit, on the eastern

coast of Eubœa, is the occurrence of large angular masses of finely crystalline dolomite in the magnesite at a depth of 90 feet, whereas at 280 feet a layer of dolomite 2 to 3 feet thick forms the hanging wall of the deposit (Fig. 2). Replacement with formation of angular inclusions is evident here, in confirmation of Bateman's theory.

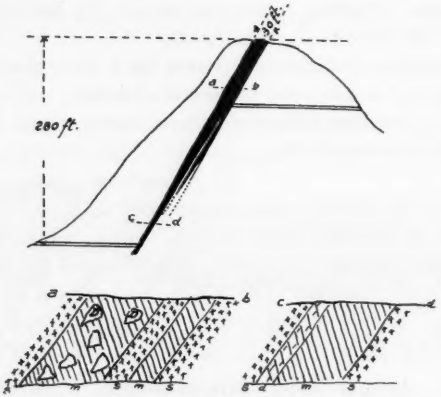

FIG. 2. Xeropotamo, vertical section. Below, magnified sections, in *B* (left) and *C* (right). *s*, serpentine; *m*, magnesite; *D*, dolomite.

This theory appears also to receive remarkable confirmation on examination, both macroscopic and microscopic, of many specimens which show incomplete replacement. An excellent illustration of this is shown in Fig. 3. The occurrence of both angular and rounded fragments of serpentine in the magnesite shows that the presence of the former only is not decisive evidence as to whether a deposit was formed by replacement or by cavity filling.

James Hogg[3] pointed out in 1913 that the Eubœan magnesite deposits were derived from serpentine through the agency of water containing carbon dioxide, and that the magnesite was deposited in fissures. The present writer believes that the original peridotite developed shrinkage cracks during cooling, and along

[3] Hogg, J., "Magnesite Deposits in Eubœa," *Trans. Inst. Min. & Met.*, XLVI., 1913.

these cracks serpentinization subsequently took place which resulted in the formation of soft serpentine. This was extremely porous, and therefore a favorable ground for the development of magnesite, which is believed to have been formed by percolation

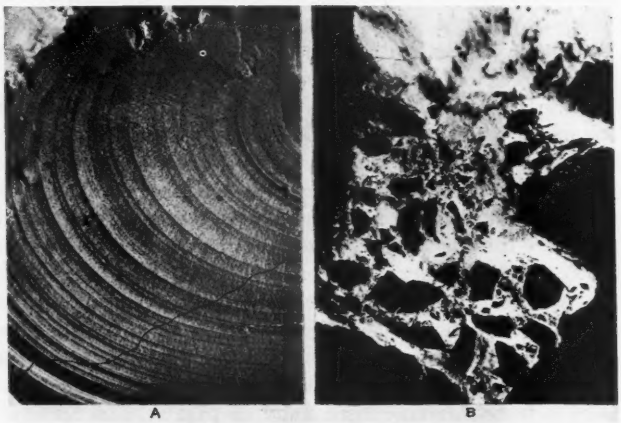

FIG. 3. *A*, colloform concentric magnesite, Limni deposit, Eubœa. × 2/3. *B*, fragments ("angular inclusions") of serpentine (black) in magnesite (white). Katugni deposit, Eubœa. × 2/3.

of surface waters under pressure. The carbon dioxide contained in these waters converted the serpentine into magnesite and silica, both in colloidal form. The magnesite, which shows excellent colloform structure in places, was deposited whereas most of the silica was carried away.

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CORBEIL,
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STRUCTURAL CONTROL OF ORE DEPOSITION.

Sir: In the interesting paper "Structural Control of Ore Deposition" which appeared in the January–February issue of this

journal, Carlton D. Hulin has marshalled a formidable array of evidence in support of his thesis that veins, and more particularly ore-shoots, are formed by "repeated filling of small openings produced recurrently by intermineralization fault movements." However, I venture to question the applicability of much of this evidence, which, after the manner of certain Latin-American armies, may at a critical moment pass over to the opponent and turn against their erstwhile leader.

At the outset I wish to agree unqualifiedly with his statement that the importance of pre-mineral faulting in mineralized regions has been largely underestimated by geologists. Much useless searching has been done for vein offsets. The reward of such a search has too often been the unfilled offset of the pre-mineral fracture. It is difficult to foretell how long a mineral solution will persist in its course along an established path or channel. This question of the path followed by a mineral solution from its source to the locus of deposition, although not stressed by the author, is really the crux of the matter. Are veins usually formed on major fault lines or rather on minor fissures? Hulin is inclined to favor the minor fissures and, on page 21, cites Spurr in support of this view. My own experience has been that jointly with veins filling major fractures, we may, in the same district, find veins with identical mineralization, filling minor fissures of insignificant displacement, and even bedding planes. The veins on the minor fissures are not necessarily less important than those filling major fractures, but eventually they lead to a junction with a major fracture. It has been possible frequently to establish this connection in the case of the Bolivian tin veins. That it would be more difficult to prove such a connection with the North American base metal veins is readily understandable when we consider that the deposition zone of these metals is much farther removed from the igneous source of the solutions than in the case of the tin veins, and for that reason the primary conduit, or let us say trunk-vein, has been exposed to the bleeding action of minor intersecting fissures over a much greater distance, and may never reach the upper regions except simply as an unfilled fissure whose connection with the veins is not apparent.

One fact, the importance of which does not seem to have been fully appreciated by geologists, is that, granting an igneous source of the mineralizing solutions, the distance between the deposition zone and the source is necessarily great. Vogt[1] estimates it at from 10 to 20 kilometers. Whereas the vein occurs in a thick sedimentary series, a distant source is self-evident; but, even where it occurs in igneous rock, the existence of a pre-mineral fault implies a thick solidified crust, cold and rigid enough to admit of faulting.

Spurr, whose observations are based on a broad experience with North American ore deposits, is undoubtedly right when he says that the great majority of veins are found filling minor fissures. Nevertheless the source is of necessity far away, and only a major fracture or an igneous contact zone can conceivably produce a channel of the length necessary to connect this source with the deposition zone near the surface. The ultimate minor fissures in which the veins are found at the surface must eventually link up with this main conduit either directly or through other intermediate channels. Since they are distinct from the main fracture, they must differ from it either in strike or in dip or in both. They may belong to an entirely different system of fracturing.

Hulin proposes that oreshoots were formed by repeated reopening of the fault fissure after mineralization had begun, and recementation of the breccia thus formed by new accessions from the source of mineralization. The nature of these new accessions will depend upon the time of reopening as measured on the zonal yard-stick; as was lucidly brought out by the author.

The whole presentation up to this point is satisfyingly plausible. But now, how about those minor fissures in which, after all, the great majority of veins are found? Are we to assume that a fault of a few feet displacement, or even less, is capable of rupturing a channel of from 5 to 15 miles in depth? Or, on the other hand, if the fissure is an upper branch of a trunk vein, while we may concede the reopening of the trunk vein to the source of mineralization, how are we to conceive of the branch fissure, or perhaps even chain of fissures to be opened by this same force?

[1] ECON. GEOL., vol. 21, p. 473, 1926.

The first surge of mineral solutions from below found a loose ensemble of fractures and followed the path of least resistance, sealing this path with vein material. Then comes a recurrent fault movement. What does it reopen? The main fault to the source? In this case, the movement can only be along that given fault, and can not affect, except very locally, the offshoots from the fault-vein. As far as the particular recurrent movements postulated by the "Elastic Rebound Theory," are concerned, the entire concatenation of offshoots from the trunk vein is indeed perpetually sealed against further intrusion of mineralization from the original source.

Admitting that this process might be mechanically possible for the special case of the trunk vein occupying the main fault that tapped the source of mineralization, the fact that the great majority of veins fall without its range of action, would in itself be a strong argument against the likelihood of its being operative in many cases, if at all.

It may be contended that a small displacement fault might reach great depths, as, for example some igneous dikes that occupy fissures which show slight dislocation. Dikes, however, have the rending force of enormous masses of molten matter back of them, and, at that, usually not as far back as the source of a vein. Even under the conception of "vein-dikes", a mineral reservoir of batholithic proportions is not presumed, and a direct connection of a small displacement fissure vein with the distant source of mineralization is, for mechanical reasons, highly improbable.

If we examine the evidence adduced by the author, we find it more or less synthesized in this statement (p. 21), "it has been the writer's experience to observe that this faulting commences earlier than the mineralization, reaches a maximum by the middle of the period of mineralization, and then gradually declines, commonly however, outlasting the mineralization." This is, for any vein, rather circumstantial history, with a wealth of chronological details. However, where such precise interpretation of the meager criteria usually presented by a vein is attempted, I fear that the personal equation of the historian must enter as the determinant factor.

On pages 24 and 25, polished surfaces of specimens of ore from a number of well-known mines are shown. The brecciation of an early deposition of minerals and recementation by a later deposition of minerals, usually higher in the zonal scale, is well shown. And that is all that is shown. Intermineralization brecciation and recementation, in so far as intermineralization implies that the cementing material is a new accession from the original source, is not shown. The specimens show that there has been disturbance (not necessarily fault movement) which has broken up the early deposited quartz, fragments of which were then included in later quartz and sulphides, all of which corresponds nicely with the factors of temperature, pressure, concentration and chemical behavior as elucidated on page 34 of the paper. In fact, if I were permitted to qualify the observed brecciation by the clumsy adjective "interdepositional" in place of "intermineralization," I would almost be able to fall in step with the author.

How, it may be asked, can brecciation of solidified vein matter be produced except by fault movement? By falls of rock within the vein while crystallization is going on, but before the entire mass has solidified; gaseous ebullition; convection currents; scaling off of crusts of mineral already formed. These phenomena are not limited to one fault plane as would be the case with recurrent fault movement, but may take place in any or all of the branches, offshoots and zigzags of a vein system. However, in order to visualize such action, we are brought perilously near to Spurr's conception of a "vein-dike." Indeed, it would seem that Hulin has unwittingly furnished Spurr with some very powerful ammunition.

In this connection, speaking of fragments of wall-rock imbedded in veins (one of Spurr's honor trumps), the author says: "The process of vein formation by accretion not only offers a more satisfactory explanation for the fragments of wall-rocks included in veins, but the presence of such fragments would be expected to be almost essential to this mode of vein formation." I can not agree in that it would explain the concentric rings of mineral around a rock fragment, which is the case that most typically exemplifies Spurr's idea of a floating fragment.

Citing an example from the Mother Lode (p. 30), Hulin speaks of oriented parallel fragments of foliated wall-rocks "spaced only a small fraction of an inch apart through vein thicknesses of several feet." This "book structure" is conceived to have resulted "through countless re-openings of the vein fissure contemporaneous with mineralization, each re-opening tearing loose a thin film of the foliated wall-rock which had frozen to the vein." That is, each recurrent fault movement had to tear through 5 miles or more of solid vein matter and country rock in order to tap a fresh supply of liquid vein matter, and yet these movements were so delicately adjusted as not to disturb the orientation of the "book structure," indeed, not even to rumple the leaves.

Fig. 11 *A* shows in plan a cross fault cutting a vein. No displacement is shown, although if we accept the conventions showing the dips of the fault and of the vein, even a very slight movement must show horizontal translation on a plan. Yet this fault of imperceptible displacement is supposed to have ruptured the sealing of a vein at right angles to it, and for a considerable length along its strike, clear down to the fountain-head.

Fig. 12 shows a fissure vein being spread apart about 100 feet by a cross-fault which shows only a very small horizontal displacement, and that on the opposite side from what one would expect if the gapping be accepted as a criterion of the direction of the fault movement. That is, we are asked to believe that a length of more than 300 feet of oreshoot is due to an opening caused by an insignificant slipping on a crossfault at right angles to the vein. Since in this case no faulting along the vein fissure itself is claimed, it would be interesting to know if brecciation and recementation were or were not noted here.

Fig. 13 suggests post-mineral faulting, but presuming that the author's field investigations have excluded that possibility, there is still no reason why the favorable zone should not be attributed entirely to the crossing of the two faults, both of them premineral. Just why the "stretching action" should have been inter-mineral instead of pre-mineral is not apparent.

Fig. 15 shows a saddle reef. In that kind of a structure it is

difficult to conceive of how such a local opening as a saddle arch could have been filled without a fault acting as an intermediary channel between it and the presumably igneous source of the mineralization. There is no difficulty in visualizing the first filling, but if second and third helpings are postulated, not only must the saddle arches be re-opened, but also, simultaneously, the feeding fault; two entirely unrelated structures, possibly separated by geologic ages. The figure illustrating the Bendigo example shows this lack of relationship. The force that would reopen the one would leave the other unaffected. Any brecciation, not post-mineral, that may be present in such a sheltered mineral by-lane as a saddle reef, would in fact rather indicate that it must have occurred during the original filling.

The author explains the mechanics of a number of structures favorable for the development of ore-shoots and illustrates with examples from actual mining fields. No fault can be found with this indexing of favorable structures. Those that are mentioned are no doubt favorable structures, but they are favorable without the necessity of invoking inter-mineralization faulting, and have long been considered so by geologists, usually for no more abstruse reason than that they furnished exceptionally loose or open channels for the ingress of mineral solutions, either primary from below or secondary from above.

The whole question of how veins were filled is still very obscure. Hulin has illuminated the subject from a different angle which has the merit of bringing to the fore certain essential factors, such as the nature of the opening and the ultimate source of mineralization. Although it seems to me that the net result of his discussion thus far has been that he has rather made a case against his thesis, nevertheless his further contributions on the subject will no doubt be awaited with a good deal of interest, and may entirely change that impression.

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REVIEWS

Geologie von Peru. By G. STEINMANN, with contributions by R. STAPPENBECK (Economic Deposits), F. SIEBERG (Earthquakes) and C. LISSON (geologic map). Pp. 448, pl. 9, figs. 271, map. Carl Winters, Universitäts Buchhandlung, Heidelberg, 1929.

For about half a century, the name of Steinmann has been outstanding among geologists who have published on Peru, and, consequently, the appearance of this book, in which he has collected and interpreted the information accumulated to date, is an event of importance to all who are interested in the geology of the Andes. It presents a comprehensive and scholarly statement of the geology, which leads logically to conclusions concerning the major episodes in the geologic history of the province that appear to be sound and well justified by the evidence on hand.

Almost three quarters of the pages are devoted to a discussion of the geologic column, in which the various formations are described, their distribution stated and the evidence for their distinction and correlation presented in detail.

The metamorphic rocks of pre-Paleozoic age at the base of the column are divided into two groups, the older consisting of gneisses and schists comparable to Archean rocks, and the younger composed of phyllite and quartzite of obviously sedimentary origin, comparable to rocks of the Algonkian in North America. The phyllite of the Cerro de Pasco district (Excelsior formation—described by the reviewer) is correlated with the younger pre-Paleozoic rocks. The period of folding and subsequent erosion which separates the phyllite and gneisses from succeeding deposits is recognized to be of major importance. It is termed the "Marañon folding," and listed as the earliest disturbance of the region for which definite evidence exists.

The Paleozoic is represented by thick shales of the Ordovician, correlated with the Caradoc and Llandeilo (*Didymograptus bifidus* fauna; Llanvirn of the English geologists) on the basis of abundant graptolites; by somewhat thinner shales and sandstones with an assemblage of fossils indicative of lower horizons of the Devonian; and by a variety of beds of Carboniferous age. The latter may be divided into two distinct divisions, a lower consisting of shallow water or continental sandstones and shales with traces of coal, and an upper consisting of marine limestone, locally overlain or even interbedded with thick volcanic deposits. The

Ordovician and Devonian deposits are most extensively developed in the southeastern part of the country. There is evidence, however, that the Paleozoic deposits, particularly those of the Carboniferous, were formed over wide areas and were not confined to the Andean zone. The close of the Paleozoic was marked by widespread uplift, erosion, and possibly some continental deposition, but no evidence of folding on an important scale is noted except in isolated areas near the Pacific coast, west of the Andean axis, where later Mesozoic beds are much less disturbed than the underlying Carboniferous formations.

The development of the Andean geosyncline is believed to have started during the later part of the Triassic, for the succeeding deposits are most thickly developed within the elongated Andean province. The Triassic is limited to a few widely separated and locally restricted areas of limestone correlated with the lower members of the Keuper (Karnisch and Norisch). Some doubt may still exist concerning certain beds at the base of the thick Mesozoic limestones in the Cerro de Pasco district, which are assigned to the Karnisch horizon on rather limited evidence. The boundaries of the formation are not adequately defined, and further investigation would be desirable.

Jurassic deposits are widely distributed throughout the Andes, but in Peru are restricted to limestones correlated with lower horizons of the Lias (the Hettangian, Sinemurian and Lotharingian), and to sandstones and shales of rather limited distribution in the north that are correlated with the upper Malm (Tithonian or Portlandian). The lowest formation of the Lias in Peru contains the ribbed type of *Psiloceras*, characteristic of the upper part of the Hettangian of Europe.[1] The Peruvian Sinemurian has *Arietites* which is Mid-Sinemurian in England, but has *Schlotheimia* which is Hettangian in England, and *Atractites* which is Triassic in Europe. The most prominent member of the Jurassic beds is termed the "Kieselkalke" by Steinmann and placed at the top of the Sinemurian—possibly extending into the lower part of the Middle Lias. Locally the beds contain abundant fossils, among which *Platypleuroceras* is mentioned, which marks the upper part of the Lower Lias in England. The Middle and Upper Lias are apparently absent. The Middle Jurassic has been found to date in only a very few places in Peru, but a fairly rich fauna is described. It contains, however, only one ammonite (*Sonninia*) which is also known in Europe, where it marks the base of the Bajocian.

The Callovian, which is strongly developed in Chile, is likewise of little importance in Peru, and is found only in the south, where, however, it seems well established. *Macrocephalites* and *Cosmoceras*, zone fossils

[1] For this and other comments on Dr. Steinmann's correlations, I am indebted to my colleague Prof. Percy E. Raymond.

of the Lower and Upper Callovian, respectively, in England are mentioned as occurring in the Tacna-Arica region. In northern Peru, a fairly distinctive formation of sandstone and shale is assigned to the Tithonian (the upper member of the Upper Jurassic), but it appears to contain a rather queer assortment of fossils. *Aspidoceras* and *Perisphinctes,* which are found in it, belong to the Corallian in England considerably below the Tithonian, whereas several Hoplitids that are also mentioned should normally be Lower or lower Middle Cretaceous. They all, however, belong to genera not known in England. Fossils other than ammonites are scarce and not helpful. More work appears to be needed in this part of the section.

The Cretaceous is represented by a thick accumulation of sediments and a small amount of volcanic material. Sandstones and shales prevail in the lower portion, with a succession of limestones above. Cretaceous sandstones are prominent in the vicinity of Lima, where they contain *Spiticeras* and other marine fossils characteristic of the Valanginian at the base of the Cretaceous. In the Cordillera, the sandstone and shale contain important coal deposits and are of continental origin. The coal-bearing sandstone is emphatically correlated by Steinmann with the Valangian-Hauterivian horizons of the Neocomian (Lower Cretaceous), on the basis of an abundant flora. The transition upward to marine limestones is gradual through shaly and limey sandstone. The first prominent limestones are correlated with Barremian and Aptian horizons of the Neocomian. The Aptian limestone is particularly persistent. It contains *Parahoplites,* the guide fossil for the highest Aptian of England. Thus, with the oldest and youngest zones accounted for, the Lower Cretaceous is very nicely established. Successive horizons are assigned to the three subdivisions of the Middle Cretaceous (Albian, Cenomanian and Turonian) and to the lower members of the Senonian (Upper Cretaceous). The only ammonite listed in the Peruvian Albian which occurs in England, is *Acanthoceras,* which is found in the Cenomanian there. The Turonian in Peru, with *Mammites,* is entirely reasonable. The Upper Cretaceous (Senonian) contains an abundant marine fauna which is described in detail and well illustrated. It contains no ammonites found in England, and correlation with European or North American deposits is somewhat uncertain. The assemblage of fossils, however, is similar to the fauna of the Lower Senonian in northern Africa.

Marine deposition in the Upper Cretaceous was brought to a close by a period of folding, which is regarded as the first phase in the development of the Andes. It is appropriately designated by Steinmann as the "Andean folding." In the long erosion following this uplift, the entire column of earlier rocks was exposed and the products of the weathering of the region were deposited as great accumulations of red gravels, shales

and sandstones with local limestone layers not only on Cretaceous formations, but even on pre-Cambrian phyllites. The "red beds," so prominently developed along the eastern flanks of the Andes from Argentine to Ecuador and in bands throughout the plateau and the western range, are assigned to this period. The deposits of the eastern zone are termed the "Puca formation," by Steinmann; the similar deposits of the western zone, which include the Casapalca and Pocobamba formations described by the reviewer, are grouped with overlying volcanic beds and designated the "Rimac formation." The former is described as Upper Cretaceous; the latter as either Upper Cretaceous or early Tertiary. The two are probably products of the same period and of approximately similar conditions. The former, however, contain some deposits of brackish water origin; the latter are almost entirely of continental type.

The red beds in the western portion of the Cordillera are succeeded by a thick accumulation of pyroclastic beds and volcanic flows, that attain great thickness and wide distribution along the main range. The author includes these rocks in his "Rimac formation." Recent work in the Casapalca district has shown, however, that an unconformity of considerable magnitude exists between the volcanic rocks and the underlying red shales and sandstones, so it would possibly be better to confine Steinmann's very appropriate name to the sediments. The term "Rio Blanco formation" is proposed by the reviewer for the entire accumulation of volcanic beds and locally included limestones that overlie the red beds. (The rocks are strikingly exposed at the junction of the Rio Blanco and the Rio Rimac along the line of the Central Railway).

The folding that deformed the Puca Formation, the Rimac formation and the volcanic beds is regarded as the second great Andean orogenic movement, and is termed the "Incaic folding." It is regarded as certainly early Tertiary, but its beginning is not definitely fixed. Igneous intrusion on an enormous scale followed the folding. Masses of granitic rocks of batholithic dimensions and numerous stocks, sills and dikes break the deformed volcanic beds and the earlier sediments. The plutonic rocks are described under the heading "granodiorite" and the finer grained or porphyritic rocks are designated as "rhyoandesites." The prevailing rock is probably close to granodiorite in composition, but Steinmann employs these names merely to signify any rock between granite and gabbro without implying a specific intermediate rock, a usage which will be unwelcome to American geologists.

The "rhyoandesite" bodies are considered the source of the mineralization by which the great ore deposits of the country were produced. With this conclusion, no geologist who has worked in the Andes is likely to disagree. The association is most striking between ore deposits and the small stocks of granodiorite and quartz monzonite porphyries that are

particularly abundant along the axis of the western range. Large areas of sediments without intrusions contain no important mineral districts; on the other hand, the main batholithic masses themselves are likewise barren. The relation between occurrence of ores and the depth of erosion is briefly discussed, but the subject is worthy of much further investigation, for the Peruvian region affords a great deal of evidence concerning the association of ore bodies with apically truncated stocks that will be of value to economic geologists. Bleaching of red sediments in the vicinity of ore bodies is mentioned, and certain other prominent phases of rock alteration are described in general terms.

The Tertiary formations include Middle Eocene to late Miocene littoral deposits along the Pacific, smaller local basins of continental beds within the Cordilleran region (Miocene or possibly in part Pliocene in age), and the areas of volcanic rocks. The evidence from these widely separated occurrences is skillfully used to build up a comprehensive statement of the recent history of the Andes. The accumulation of the thick, shallow-water deposits of the northwestern oil fields is tentatively correlated with the degradation of the highlands formed by the "Incaic folding" and the subsequent igneous activity. The intensive block faulting of the north coastal region is correlated with the warping and minor faulting of the interior continental deposits. It is termed the "Quechua deformation" and is placed in the Pliocene. The creation of the Puna surface of low relief by the long continued erosion following this disturbance is regarded as the closing episode of the period.

The elevation of the present mountain range, resulting from the uplift of the Puna surface, is thus assigned to the Quaternary. The three well marked stages of its dissection (the Junin, Chacra and Cañon stages) are described, and correlated with marine terraces and corresponding deposits along the present coast. Short chapters are devoted to Quaternary vulcanism and to glaciation.

A section of seventy-five pages by R. Stappenbeck contains a useful summary of available information concerning economic deposits. Certain short-comings with respect to the major mineral districts are largely to be attributed to the lack of published descriptions based on modern studies. A short summary of data on Peruvian earthquakes by F. Sieberg forms the concluding section of the volume.

The bibliography contains over five hundred titles, adequately stated and conveniently arranged. The abundant geological literature, however, is somewhat uneven in quality and needs to be used as Dr. Steinmann has used it, with considerable discrimination.

The map included with the volume was necessarily based largely on observations of reconnaissance nature, for very little close geologic mapping has been done in Peru, and almost none has been published. It

serves, however, to give a generalized picture of distribution of major formations, and accuracy in detail could hardly be expected.

Dr. Steinmann's book will probably stand for many years as the most comprehensive account of Peruvian geology, and it will be of great value to all who are attracted by the many magnificent problems that the region offers. The volume, as a whole, is an admirable piece of work.

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The Copper Deposits of Michigan. By B. S. BUTLER and W. S. BURBANK, in collaboration with T. M. BRODERICK, L. C. GRATON, C. D. HOHL, CHARLES PALACHE, M. J. SCHOLZ, ALFRED WANDKE and R. C. WELLS. United States Geological Survey Professional Paper 144, pp. 1–238, 1929. (Accompanied by a folder containing 51 plates showing geologic maps and cross sections.)

The Lake Superior copper district was opened in 1844 as a result of the studies of Dr. Douglass Houghton, first State Geologist of Michigan. The first mine opened was the Cliff mine, which worked a fissure vein in the north part of the district. The total production of Michigan to 1925 was 7,504,265,441 pounds of refined copper. The district ranks second among the copper districts of the United States. From 1906 to 1923 the average yield per ton of rock was 25.2 pounds of copper or approximately 1¼ per cent.

The first comprehensive geological report of the district was that published by Pumpelly of the Michigan Geological Survey in 1879. This was followed in 1883 by a monograph, No. 3, of the United States Geological Survey by R. D. Irving, Lane's report by the Michigan Survey appeared in 1911, and Van Hise and Leith treated the geology of the district in a general way in their monograph on Lake Superior, No. 52 of the Federal Survey. Notwithstanding its great interest and the great production of the district the United State Geological Survey has not published a detailed monographic report on the district since the paper by Irving, which was issued before many of the mines were opened. Those who are interested in the genesis of ore deposits and particularly in the genesis of the unusual and very valuable copper deposits of Michigan, will feel that their patience is at last rewarded by the appearance of this volume, the excellence of which is guaranteed by the high character of its authorship. The paper is clear, concise, well arranged, and considering the great area covered, is comprehensive.

The area described extends from Keweenaw Point southwest to the Wisconsin boundary, thus including the White Pine district of Ontonogan County. In late pre-Cambrian or Keweenawan time a series of basaltic

flows thousands of feet thick were extravasated. These flows are interbedded with felsite conglomerates which are abundant in the lower part of the series, relatively rare in the middle part, and in the upper part make up the bulk of the system. Intruded into and probably interbedded with the basalts are acidic rocks similar to those that make up the pebbles of the conglomerate. It is thought probable that the fissures through which these igneous rocks rose are located in the basin of Lake Superior and that they flowed outward from them in the direction opposite to that to which the beds now dip. Both the lavas and conglomerates were deposited in the main on land, although some of the later conglomerates were probably deposited in water. The intrusive rocks are mainly siliceous although some are basic; they approach the Duluth gabbro in composition and texture and were probably derived from the same source as the Duluth gabbro. The flows range in thickness from a few feet to 1,300 feet. Their tops are vesicular due to gases that expanded at the times of their formation; some of the tops are fragmental and commonly they are oxidized. These cellular porous tops of the flows have provided channels for movement of solutions.

The lavas dip northwest into Lake Superior basin. The lower ones dip steeply, the later ones less steeply. Cross faults dip northwest down the dip of the flows. The Keweenaw fault strikes southwest along the center of Keweenaw Point. It is a reverse fault, dips northwest and on its east side is found the "Eastern" sandstone of Cambrian age. It forms the southeast boundary of the copper bearing area. Numerous faults and fissures branch from it. Movement on this great fault probably began in late Keweenawan time and it continued after the "Eastern" sandstone was deposited.

The copper deposits include "lodes" and fissure deposits; the lode deposits include conglomerate deposits which are mineralized beds of the conglomerates interbedded with the basalt flows, and amygdaloid lodes, which are the mineralized vesicular or brecciated tops of the lava flows. The fissure deposits are narrow tabular veins that lie parallel to the beds or in places cut across them. The valuable lodes are nearly all in the Keweenawan series, composed predominantly of lava flows. They are distributed through most of that part of the series and the most productive lodes from the base up are: Baltic, Isle Royal, Kearsarge and Osceola amygdaloids; the Calumet and Hecla and the Allouez conglomerates; the Pewabic and Ashbed amygdaloids. The Nonesuch lode is in the upper Nonesuch formation in the upper sedimentary portion of the series. The fissure deposits are in that portion of the series which contains most of the lodes.

Of the conglomerate beds two only are extensively explored, the Calumet and Hecla conglomerate and the Allouez conglomerate. The Calumet

and Hecla is generally sandy. At Calumet it becomes a felsite conglomerate bed which increases in thickness and width with depth. The mineralized portion is confined to the conglomerate lens and the copper content decreases where the conglomerate changes to sand. The copper occurs as native metal and replaces the fine matrix of the conglomerate. The gangue minerals are feldspar, epidote, quartz and calcite. Zeolites are absent. The Allouez conglomerate is generally thicker and more persistent than the Calumet conglomerate, but at places it is represented only by a clay seam.

Of the amygdaloids that have yielded important amounts of copper, all but two are of the fragmental type. These fragmental tops of flows are formed by breaking up of cellular or vesicular tops of the lavas into angular fragments during solidification. The Pewabic lode is partly fragmental and partly coalescing; that is, at places the union of gas bubbles collected during cooling to form continuous openings, which are separated by layers in which cavities are rare. The Ashbed amygdaloid is locally fragmental but is mainly an "amygdaloidal conglomerate,"—a clastic rock formed of sand and pebbles of basic rocks and boulders of amygdaloids. A greater variety of minerals are found in the copper ore in the amygdaloid than in the conglomerates. These include: chlorite, feldspar, epidote, pumpellyite which preceded the deposition of copper, quartz, calcite, some prehnite and datolite, which at places were deposited with native copper; the zeolites—laumontite and analcite—which were deposited later than copper. Sericite was deposited with and also after the copper. The alteration of the rock along the amygdaloid lodes was of two types: (1) removal of hematite and (2) partial reduction of ferric oxide in hematite to form ferrous oxide and recombination to form such minerals as pumpellyite, chlorite and epidote.

The ore shoots were deposited in the more permeable parts of the lodes. The Calumet and Hecla conglomerate is generally impermeable, but contains permeable portions of great downward extent, and these were the parts that were metallized. The Osceola amygdaloid is generally permeable but contains impermeable streaks. These streaks are not metallized but the ore occurs just below them. They appear to have served as barriers for rising waters.

Mineral veins are numerous in the district and many of them have been worked. In the north end of the district the veins cut across the beds. In the south end of the district they strike with the bed, but dip at steeper angles than the beds. In both parts of the district the ore shoots in the fissures are near strong conglomerates or amygdaloids.

The theory that has generally been accepted to account for the origin of the copper deposits is that descending ground water has leached the copper from the lavas and deposited it in the more open parts of the

conglomerates, amygdaloids and fissures, reacting with the ferrous iron of the lavas to form ferric compounds and metallic copper. Another theory is that the ores were deposited by ascending waters that derived the copper from an igneous source and that the reactions of the solutions with ferric iron of the rocks resulted in the oxidation of the solutions, the reduction of the ferric iron and the precipitation of native copper. The first theory is excluded because, although the lavas do contain copper there is no evidence of its removal and moreover there is no evidence of a deep circulation of water in the mines today. Many of the deposits, as already stated, lie on the under sides of impermeable barriers, which is strong evidence of ascending waters. The deposits were formed in the main in beds rich in ferric iron and poor in ferrous iron and the ferric iron was partly removed and partly reduced to the ferrous state. This reaction would not likely take place in oxidized solutions. The source of the ascending waters, according to the theory proposed by the authors, is believed to be the Duluth gabbro which probably underlies the area.

The section of the report that treats the genesis of the deposits is a masterpiece of clear and logical reasoning, and will stand as a mile post marking the advance of economic geology. The authors bring together a brief review of the structural conditions that existed in the area as they affected the paths of solutions, and the chemical environment of the paths of the solutions. They conclude that the solutions that deposited the ore were such as ordinarily would have deposited copper bearing sulphides if they had encountered rocks of the ordinary composition. But because they encountered rocks with a high content of ferric iron certain chemical changes took place. The iron of the wall rock was reduced and the sulphide bearing solutions were oxidized. Copper was deposited as native metal and sulphur compounds became sulphates which were carried away. The Lake Superior copper ores are unusual not because they have been deposited by solutions of an unusual character, but because the solutions moved through wall rocks that were unusual and particularly because the wall rocks contained large amounts of ferric iron.

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Estudio Metalogénico de la Sierra de Cartagena. By RICARDO GUARDIOLA. Mem. Geol. Inst. of Spain. 562 pages, 16 maps and plates, 105 text figs. Madrid, 1927. Price, 15 pesetas.

This monograph is the culmination of 39 years of work on the ore deposits of southeastern Spain by this well known Spanish mining geologist. It is a description of the geologic history, stratigraphy and genesis of the

ore deposits of the region to the east of the town of Cartagena, Spain, and consists of four chapters as follows: Chap. I, Orography, Chap. II, Stratigraphy, Chap. III, Tectonics, and Chap. IV, Metalogenesis.

A series of anticlines striking E.-N.E. were generated during the period of Hercynian folding. Two systems of roughly parallel faults were developed on these anticlines toward the end of the Triassic—parallel and at right angles to the strike of the anticlines. A series of deep-seated intrusions of ophites, diorites, diabases and dolerites occurred along the transverse faults at the end of the Triassic, accompanied by the formation of deep-seated veins of galena, sphalerite and pyrite in slates and schists of late Paleozoic age, and replacement deposits of galena, sphalerite and pyrite in the limestones and marls of doubtful Triassic age and in lenticular masses of crystalline limestone contained in the Paleozoic slates and schists. The origin of the rich ore body in the slates and schists, known as the "Manto de Azules," is vaguely explained as a "lateral injection" of magmatic emanations into a porous and highly fractured zone in the slates and schists. The injection is supposed to have taken place at great depth and at high temperature.

At the end of the Miocene, during the close of the period of Alpine folding, the faults parallel to the strike of the anticlines were reopened and laccoliths of andesite, trachyte and liparite were intruded along these faults into calcareous conglomerates, marls and sands of Miocene age. These intrusions gave rise to a series of veins of galena, sphalerite and pyrite in the intrusive igneous rocks, and replacement deposits of galena, sphalerite and pyrite in the calcareous conglomerates and marls of Miocene age, with some impregnation of the sands.

Through erosion and leaching of the Triassic limestones, the galena and pyrite were converted into cerussite and various hydroxides of iron and concentrated, in part, at the contact between the Paleozoic metamorphics and the overlying Triassic limestone. A third series of basaltic intrusions occurred in the Quaternary, but these were not accompanied by important mineralization.

The region appears to have a very complex history and contains a great variety of veins in addition to the predominant galena-sphalerite-pyrite type. Many chemical analyses of the ore bodies are given but definite mineralogic descriptions are conspicuously lacking. The gangue minerals are chiefly described as carbonates, silicates, and hydroxides of iron, frequently without mention of the specific minerals present.

The monograph gives such an excellent and full account of the geology of the district that the economic geologist will be somewhat disappointed at not finding the account of the mineralization up to the same standard.

ERNEST C. H. ROSCHEN.

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Gravity Surveying in Great Britain. By H. SHAW. 14 pp. A. I. M. E. Tech. Pub. No. 74, 1928. Also in A. I. M. E. "Geophysical Prospecting, 1929," pp. 530–543.

The intensive torsion balance work in Great Britain has been in connection with the location of usually large and irregular deposits of iron ore. The situation was complicated by the presence of 0 to 250 feet of heterogeneous glacial drift, a subdrift topography with considerable relief on limestone, and numerous faults. On account of the superficial heterogeneity seriously affecting the differential curvature, it was neglected and only the gradient was used. A station interval of 100 and in some cases 50 ft. was used. Many details of the field practice are given. The paper unfortunately is not illustrated with any of the results of the survey.

D. C. BARTON.

Computation of Eötvös Gravity Effects. By E. LANCASTER-JONES. 55 pp. A. I. M. E. Tech. Pub. No. 75, 1928. Also A. I. M. E. "Geophysical Prospecting, 1929," pp. 505–559.

This paper summarizes practically all the known formulae for the calculation of Eötvös gravity effects. Many of the formulae are given in a mathematically pretty, but very condensed, notation, which is rather forbidding to the uninitiated but becomes clearer after a little study. The formulae are handled under the headings of formulae for:—point elements, line elements, terrane features, topographical features, cartographic features, three dimensional features bounded by plane surfaces, irregular three dimensional figures (Nikiforov's method), and change of axes.

This paper is a most useful compendium of formulae.

D. C. BARTON.

Report of Committee on Sedimentation, National Research Council, 1927–1928. By W. H. TWENHOFEL, Chairman. Reprint and Circular Series No. 85. 83 pp. Washington, D. C. Price, $1.00.

The contents of this report may be gained from the following eleven titles included in it: Introduction, W. H. Twenhofel; Research on Sedimentary Rocks by British Petrologists, H. B. Milner; Recent Work on Bentonite, C. A. Bonine; Varved Sediments, E. Antevs; Chemical Studies on Sedimentation, G. Stieger; Studies on Coarse Sediments, 1923–1927, C. K. Wentworth; Salina Formation, D. H. Newland; Glacial Sediments in 1927, M. M. Leighton; Bacterial Agents in Sedimentation, G. A. Thiel; Sedimentary Deposits in the Desert, Eliot Blackwater; Soils which bear on Sedimentation, H. H. Bennett.

BOOKS RECEIVED.

New Calibrating Device Aids Work with the Magnetometer. By L. SPRARAGEN. Oil and Gas Journal, vol. 27, No. 40, Feb. 21, 1929, p. 118.

A calibrated coil is used to set an electromagnetic field of controlled strength. The device consists of the calibrated coil and an instrument panel with an ammeter, potentiometer, a set of resistances, switch and 2 dry cell batteries. The coil is designed to fit around the magnetometer.

Home of "Gator" and Water Lily Opened for Oil by Science; "Dynamite Buggy" and Pirogue are Tools with which wildcatters seek domes in Louisiana Swamps. By WALLACE DAVIS. The Oil Weekly, vol. 52, No. 27, Feb. 1, 1929, pp. 69–76.

A popular account of field practice with the seismic method in the Louisiana swamps, illustrated by many interesting photographs of characteristic phases of the work.

The Seismograph in the Gulf Coast. By MARK C. MALAMPHY. The Oil Weekly, vol. 52, No. 5, Jan. 18, 1929, pp. 31–34.

This paper gives an excellent succinct popular statement of the seismic method of prospecting for salt domes, as it is actually used in the Gulf Coast. The paper is illustrated with a characteristic "shot" map and time distance curves.

D. C. BARTON.

Earth Flexures: Their Geometry and Their Representation and Analysis in Geological Section with Special Reference to the Problem of Oil Finding. By H. G. BUSK. Pp. 106, figs. 92. Cambridge Univ. Press, 1929. Macmillan Co., New York. Price, $4.00.

An interesting analysis of structure. Chapter VI. (pp. 69–104) treats of Tertiary structure in petroliferous rocks of Burmah, Southwestern Persia and the Gulf of Sinai.

Geology of the Marysville Buttes, California. By H. WILLIAMS. Univ. of California Pub. vol. 18, no. 5, pp. 103–220. Pl. 10, figs. 13, map. Berkeley, 1929.

A Neocene Erosion Surface in Central Oregon. By JOHN P. BUWALDA. 10 pp., one plate, one text figure: The Dalles and Hood River Formations and the Columbia River Gorge. By John P. Buwalda and Bernard N. Moore. 26 pp., one figure. Carnegie Inst. of Wash., June, 1929.

Geological Survey of Poland, *Bulletin,* Vol. IV, Livr. 3–4. Pp. 764, Pl. 13, figs. 9. In Polish and French. Warsaw, 1928. (July, 1929.)

SCIENTIFIC NOTES AND NEWS

C. K. Leith, of the University of Wisconsin, led a general conference in August at the Institute of Politics, Williamstown, Mass., on the subject of Canada's minerals in their international relations.

Olaf P. Jenkins has been appointed chief geologist of the California Division of Mines and has taken charge of the newly established Geologic Branch.

L. C. Graton, professor mining geology at Harvard University, recently visited Salt Lake City, Utah, to consult with the legislative advisory commission of the State and the State tax commission regarding taxation and mine valuation.

Keith Allen, mining engineer of Rhodesian Broken Hill Development, is spending a few months in the United States mining camps studying their methods.

H. C. Richards, professor of geology and Mineralogy at the University of Queensland, Australia, went to Cape Town this summer to visit gold and copper fields as a member of a royal commission on the mining industry in Queensland, also to attend the International Geologic Congress as official delegate of the Australian Government.

Harold T. Stearns, of the U. S. Geological Survey, has been conducting an investigation of geology and underground water resources of the Snake River region, southern Idaho, and maps have been prepared covering an area of over 16,000 square miles.

The fall meetings of the A. I. M. E. present an unusually extensive program, with meetings at Cleveland, Sept. 9–12, Spokane, Oct. 3–5, Tulsa, Oct. 3–4, Los Angeles, Oct. 4–5, and a final meeting at San Francisco, Oct. 7–10, from which delegates to the World Engineering Conference will sail for Japan on Oct. 10.

At the World Engineering Congress in Tokio the following official delegates will represent the A. I. M. E.: H. F. Bain, G. D. Barron, F. W. Bradley, J. V. N. Door, B. E. Eldred, J. R. Freeman, H. D. Hibbard, J. C. Hoyt, C. K. Leith, P. M. Lincoln, F. F. Lucas, C. W. Merrill, M. L. Requa, J. V. W. Reynders, R. H. Richards, G. O. Smith, and W. Y. Westervelt.

Horace Bushnell Patton, professor of geology and Mineralogy at the Colorado School of Mines from 1893 to 1917, died on July 15 at Atascadero, Calif. Since leaving the Colorado School of Mines he had been engaged in professional work.

George Perkins Merrill, for 32 years head curator of the department of geology in the U. S. National Museum, and author of well-known works on geologic subjects, died suddenly on August 15 of heart trouble. He was born in Auburn, Maine, in 1854.